SCIENCE FOR EVERYONE

G. ZELKIN

FLYING TRAINS

MIR

Science
for Everyone

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Летающие экспрессы

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At the Start of a New Transportation Method

> It is impossible to convince people of a novelty. One has to wait for a new generation to accept new ideas.
>
> MAX PLANCK

The idea of a train supported on an air cushion or magnetic suspension rather than wheels came to the author as far back as 1957. At the time almost nothing had been written about such vehicles, while the idea itself aroused scepticism. Today these vehicles are regarded as a new and promising mode of transportation, they are being developed, and are under construction or being operable in many countries. The author did not just witness the debate that accompanied the development and establishment of this new form of transportation in the Soviet Union, but took an active part in it.

Ideas, like people, are sometimes born easily and sometimes with pain, and their fate too may be different. That of wheelless trains as a practicality has not been all roses.

In *Wheelless Trains* (published in Russian by Znanie Publishers in 1974), V. A. Drobinsky writes: "After long years of scepticism over the value of high-speed wheelless trains, attitudes have changed considerably. The continuous growth in passenger traffic, especially in the densely populated regions of the developed coun-

tries, is putting an ever increasing demand on the transport system requiring speeds that are unattainable by ordinary railway technology... Only recently many experts have smiled when talking about wheelless trains but in spite of all the problems these trains figure significantly in transportation forecasts for the near future... There is now a considerable research and development experience (more than 14 years) of tracked air cushion vehicles (TACVs). They have been modelled, scaled up, and track tested over long track sections at remarkable speeds. A development scheme has now been devised for such trains, and a good deal of theoretical and experimental data has been acquired that is of considerable design interest."

This quotation illustrates the evolution of the treatment of hovertrains (as tracked air cushion vehicles were dubbed by the general public) by the experts. The time has not passed unused, and Victor Hugo was right when he said that no army can stop an idea whose time has come.

It is often asked how a new idea occurs. It would be romantic if it had been a motorist somersaulting in the air after a punctured tyre who first thought of a wheelless vehicle. In fact, the desire to eliminate the wheels came after a long period of thought about how transportation speeds could be increased.

At the time the first space flights were being made, and an enthusiastic public was being to regard ordinary vehicles as old-fashioned, it became obvious that a sharp increase in speed would require drastically new ideas. The appearance of hydrofoils aroused a great deal of enthu-

siasm; it was admired for its new engineering philosophy. The first space launchings instilled confidence in the potentials of science, and eliminated any fear of the yet-untapped engineering concepts.

It is quite obvious, however, that the simple replacement of a wheel by an air cushion or magnetic suspension could not convert a vehicle into a new form of transportation. To be viable it would have to be economical, too. Ways had to be found to reduce the power requirements; two were adopted: (i) to reduce the hover height, and (ii) to eliminate, partially or completely, the train loading on the cushion. We note in passing that the first goal could be achieved simply by laying down a specially prepared smooth surface, a guideway.

At first, magnetic suspensions seemed to be a more attractive proposition than air cushions. Indeed, it could be established with the power source outside the vehicle, its operation being quiet. It was uncertain however how much energy would be needed to produce a magnetic field that could support the train. Fantastic amounts of energy were estimated as being required to support a vehicle in a dynamic magnetic field, permanent magnets being useless for this application. Accordingly, the idea of magnetic levitation was deferred until later and all the research work was focused on air cushions.

Tracked air cushion vehicles (TACVs) have no wheels, and it was decided that the track should be a monorail with a smooth supporting surface. This design enabled the vehicle to be suspended with only a millimetre thick cushion,

which is virtually an air film. Analyses indicated that this air-lubrication system would need a reasonable power, so the train seemed feasible. The author derived an analytical relationship between the gross weight of the vehicle and the energy expended in the production of the air cushion. In order to unload (partially or completely) the air cushion, the author suggested using aerofoils. These, however, are known only to perform effectively at high speeds. But it is at high speeds that the unloading is most wanted, since this is when most of the power is needed to overcome the drag. Apart from that, some consideration had to be given to the provision of additional lift at low speeds or at train stops, when the wings would not work.

It was proposed that the jets of the propulsion engines be used as the additional source of lift. The jet emanating from a thrust nozzle must be guided to a channel installed on pylons. Because of the different velocities of the jet and the surrounding air relative to the train there is an upward pressure gradient. The lift due to this gradient will be greatest at stops and will gradually decrease as the train gains speed (provided the jet velocity is the same). Some unloading for the train's power unit can be provided at stops, where compressed air can be supplied by stationary compressors or gas cylinders for the air cushion.

During the years of the project's development, the winged TACVs have grown into a promising mode of transportation. It has been recognized that the trestle on which a monorail will have to be mounted because of high train speeds will

not penalize the cost effectiveness of the project, but will rather be an advantage when routing the train through swamps or permafrost regions. To cope with the noise generated by TACVs a new idea, the linear electric motor, was dreamt up. Here an electric motor is "unrolled" along the monorail and used to provide the traction. Exploration work had by then begun on guided vehicles supported by dynamic air cushions all over the way.

For a certain period of time, however, the hovertrains and the associated projects failed to come home. A few applications for patents on winged TACVs were withheld in the 1960s "because they were worthless" The author found himself in a situation very much alike that of Cristopher Cockerell, a British radio engineer, who had suggested an air supported skimmer to the British industry in 1955. Cockerell recounted that industrialists did not want to get involved in the idea. 'Your project has nothing to do with aircraft, go to shipbuilders', airplane manufacturers would say, while shipbuilders used to say 'What you suggest is obviously not a naval vessel, go to aviation'. The situation was compounded by the absence of appropriate patents.

In 1966, France announced the construction of a 6.7-km test section for TACVs. A four-seater vehicle, named *Aerotrain-01*, was run at 170 km h^{-1}. The next modification, the *Aerotrain-02*, was developed and in 1968 attained a maximum speed of 378 km h^{-1}, breaking the world speed record for rail vehicles in tests.

The French vehicles were essentially the same design as the TACV developed by the author. The

system involved a single vehicle on a trestled monorail. The air cushion was generated by fans driven by an individual power unit. Two tur-

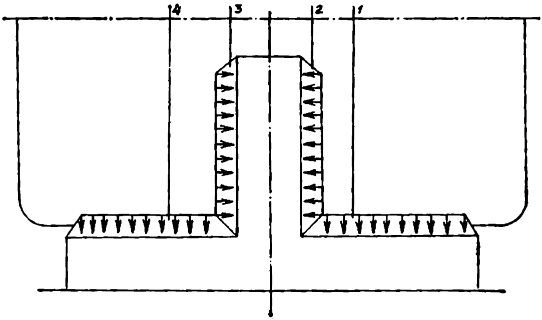


Fig. 1

boprop engines were used for propulsion. The train was capable at a design maximum speed of 430 km h^{-1}, and carried 180 passengers.

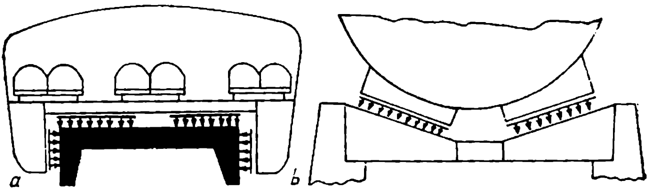


Fig. 2

In addition to the inter-city express *Aerotrains*, the same French company developed commuter and cross-country aerotrains. The supporting

track was an inverted T in cross section (Fig. 1). The air cushion was produced by two groups of nozzles: one group (nozzles *1* and *4*) shaped the cushion over the horizontal surface of the mono-

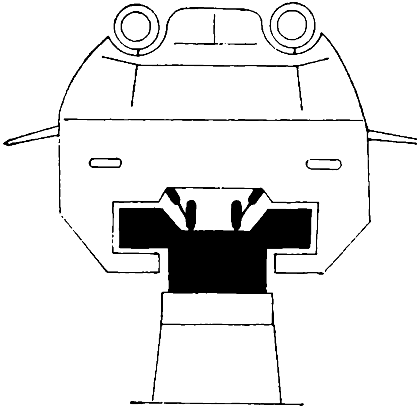


Fig. 3

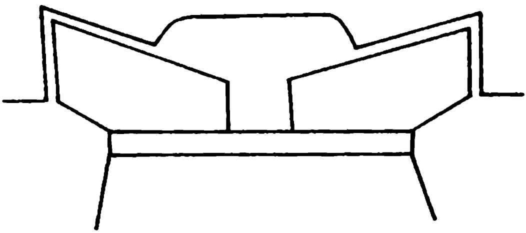


Fig. 4

rail to support the train, the other (nozzles *2* and *3*) created the cushion on the side flanges to provide for lateral stability. To attenuate the noise of traction, the cross-country version was

driven by an ac linear electric motor or by two rollers pressed to the vertical fin of the track.

Britain followed France and also tested hovertrains. The model of a TACV was tested in 1966 and called *Hovercar*. The track-train coupling concepts of the British system differed from the French configuration (Fig. 2), but it is quite apparent that they are similar to the designs of the author shown in Figs. 3 and 4.

In the Soviet Union, the TACV was officially recognized as a new mode of transportation at the All-Union Conference on Air Cushion Vehicles in Tyumen in 1972. This fact was aided a great deal by press publication, notably in a number of leading papers and the popular technical magazines *Tekhnika molodezhi* and *Izobretatel i ratsionalizator*. The Soviet Union joined the TACV club in 1974, contributing to the development of air and magnetically supported trains.

How to Make the Distant Closer

Life is wonderful also because
there is always place for travel.

MARTIROS SARYAN

Travel and Progress of Civilization

Widely opened eyes and uncertain steps... that is my image of a child entering the world. He gets to know about his surroundings by asking "How far?", and our understanding of the world and movement in it are intimately bound up with the question throughout our lives.

Our environment is a source of information for understanding. The more a person travels, the more impressions he receives and the richer intellectually he becomes. Travel broadens the mind. Important geographical discoveries raised the advance of civilization, whilst dealings with other peoples aided in the exchange of ideas, and opened up the riches of science and art in different centres of culture around the world.

Before the mass media appeared, the intellectual levels of urban and provincial people differed a great deal. The development of science and technology has diminished distance on the planet as a factor hindering information exchange. Moreover, man has learned how to get information about location he has never been to.

Nonetheless, the presence of man in unexplored areas is necessary. Experience suggests that despite the most advanced automation and tele-

metry, and remote control, the presence of man is essential aboard orbital stations and in exploratory missions to other planets. Now, as ever before, our understanding is intimately connected with travel over large distances. "How far?" remains a major question for the evolution of human knowledge.

Speed and Technological Progress

We live in a four-dimensional space. Three dimensions define position, and the fourth is time. When we learn about the world we cannot move it closer as it exists independently from our consciousness. The only way to expand the boundaries of the space we study is by influencing the fourth dimension, time, through increasing the speed of travel. The question "How far?" then becomes a relative one in that a location may be distant or close depending on the speed with which it can be reached. Therefore the rate at which we increase the speed of motion is a factor in progress. The speed at which a community can transport its members is indicative not only of the state of the art of its transportation but also of its level of science and technology. From a value of maximum speed we can infer the time it was attained.

Suffice it to say for example, 30-35 km h^{-1} and we know we are talking about the era of horse and carts. A maximum speed of 150 km h^{-1} means the early twentieth century, when the first airplanes took off. Crossing the sound barrier came with jet aircraft and signifies the early mid-twentieth century. The orbital velocity

(7.91 km s^{-1} at the Earth's surface) refers us to an exact date: October 4, 1957, when the first Earth's satellite, Sputnik, announced to the world the beginning of the space age.

The orbital velocity was followed by the escape velocity of 11.2 km s^{-1}. This velocity is sufficient to overcome the force of gravity. Accelerated to this velocity, a body leaves the Earth's gravity field along a parabolic path to assume a solar orbit. The maximum speed of a man-made space vehicle is 16.66 km s^{-1}, the solar escape velocity. At this velocity a space rocket overcomes the gravity fields of first the Earth and then the Sun to leave the solar system. Both the second and third space velocities are related to specific dates.

The next space velocity to be reached will be for Galaxy escape and it will enable spacecraft to leave our Galaxy. The date this velocity becomes a reality will be a milestone in the history of mankind.

Apart from the absolute speed records, there are record velocities for each mode of transportation—travel by water, ground, air, and space. For example, ten knots (17-19 km h^{-1}) for ships revives old times when sailing ships dominated the oceans.

It is not always true though, that a high transportation velocity is able to bring the distant closer. Sometimes a desired location is "around the corner" and yet cannot be reached because there isn't a vehicle available with the necessary cross-country capability. Away from a highway a fast car is less efficient than a cart. There is even a proverb that roads are expensive, but the lack of roads is more so. Some locations are even

impassable for carts, then a helicopter is indispensible. However, helicopters are relatively uneconomical and so are only used in special situations. Therefore, speed is not the only criterion for any vehicle; cross-country capability and operating economy are also important.

Hence, the problem of "bringing the distant closer" is not just a transportation one but also has social implications whose solution depends on the level achieved by mankind.

Transportation and Mankind

> Three things make a nation into a great and thriving one: fertile soil, efficient industry, and ease of moving people and goods.
>
> FRENCIS BACON

The Development of Transportation

In the complicated body of a community, transportation is like the circulation system. It grows in significance as the economy advances. A good transportation network is essential for the rational use of economic potential, the improvement of the quality of work, and the economical use of resources. There is no human activity that is now independent of transportation. This is a consequence of the fact that the development of a community is inseparable from the development of transportation. The exploration of unknown areas and spread of man across the planet could only be done after the development of transportation.

These were primitive vehicles in the early civilizations. As the population grew, newer territories were populated, and this would have been impossible without transportation. A growing civilization accelerated commodity production, increased labour productivity, and led to the construction of machinery. During the 15th and 16th centuries transportation began to separate into an industry, and this process was completed in the last third of the 18th century when commodity production grew from small-scale manufacture to large-scale machined production.

Mechanized transportation considerably influenced the development of industry and trade, and boosted social change in various countries. A variety of vehicles were developed for different needs. Transportation developed according to a major dialectical law, by way of which the gradual accumulation of quantitative changes in each mode of transportation eventually brings about considerable qualitative modernizations.

The modernization of existing vehicles is a gradual process of quantitative alterations, improvement, and operational development. Eventually quantitative alterations have to bring about qualitative ones. This transformation materializes in the appearance of an essentially new form of transportation, harnessing pioneering ideas, to include inventions such as wheeled transportation, aircraft, winged trains with air-film lubrication, trains with magnetic levitation, and space tugs.

The development of vehicles proceeds in two directions, namely, an improvement of existing designs and a development of new ones. Each mode of transportation—ground, water, air or space—has its own history which indicates that development has mainly occurred via the advancement of existing vehicles. Qualitative changes in transportation mode are extremely seldom.

Any vehicle can be advanced by improving its units, assemblies and components, and alterations can be introduced in the design and production technology. This protracted process may sometimes create a situation in which a more advanced design is unable to compete with an existing one which is operationally developed.

This thesis may be illustrated taking the pis-

ton combustion engine as an example. By its operating principle this engine is inferior by far to the turbojet engine. The latter has none of inertial mass of a reciprocating piston assembly. However, the piston engine has been developed for so many years and so much capital has been invested in the production of these motors that if it were decided to power motor cars by a more progressive motor, the necessary investment would take several tens of years to be amortized.

By the mid-1950s water transportation had become the slowest one. The increase in speed for water craft lagged far behind those for ground and air vehicles. Over the last two centuries the speed of ships approximately doubled; from 17-19 km h^{-1} (sailing ships at the time of the Peter the Great) to 40 km h^{-1}. There were specialized vessels (torpedo boats, for instance) which could attain speeds of 70-80 km h^{-1}, but only by large and uneconomical expenditures of power. Of course, torpedo boats cannot be viewed as transportation facilities. Thus, the problem of increasing the speed of a transport ship could not be solved by raising the power of its motor only. Qualitatively new design solutions were required therefore to increase the speeds of ships, and such solutions were found. There appeared vessels supported by hydrofoils.

The main difference between a hydrofoil and an ordinary displacement ship is the former's much lower resistance to motion. This reduction is achieved by a foil which lifts the ship's hull above the water.

A similar principle is used in aircraft. Aerodynamic lift is generated by the air stream

flowing around the aircraft's wings. However, the density of air is approximately 800 times lower than that of water. Therefore, to produce the same amount of lift in water a much smaller foil area is required. The smaller foil surface means that the wing can be smaller and hence the hydraulic drag it causes will be lower.

When a hydrofoil picks up speed, its foils produce a vertical lift sufficient to raise the hull above the water. The foils are then the only structures that remain submerged and they cause a low hydraulic drag. This low resistance to motion allows these ships to be considerably faster at the same power expenditure.

A foilborne craft is a qualitatively new means of transportation. The need for a qualitatively new design also emerged for transporting ore from deep open pits. Today this job is performed by dump trucks with loading capacities of up to 75 tonnes. Heavier trucks with 120-tonne capacities are being tested. Nevertheless, the efficiency of this type of transport in quarries that are several hundred metres deep decreases by 15 to 20% every five years. This is because the specific horsepower of the engines used (5-7 HP per tonne weight) is insufficient for the vehicles to climb long sustained upgrades at reasonable speeds. As a result dump trucks move along them at speeds of 8-10 km h^{-1}, which impairs the overall throughput.

The use of electric motors cannot solve this problem because the diesel engine of the electric generator driving the motor-in-wheels operates at virtually the upper limit of its power. On the other hand, the design of a combustion engine

for 100-120-tonne trucks is an extraordinarily difficult engineering challenge. The scope for improving the existing vehicles is being exhausted. Consequently, a new approach is required.

A technically feasible approach would be to power the trucks from an external source. Trucks like this were proposed in this country about forty years ago by Professor A. S. Fidelev who called them trolleytrucks.

This is a rather limited, but qualitatively new solution which would go beyond just the improvement of existing truck designs and make it possible to devise a new vehicle.

Social Implication of Transportation

The development of transportation as a whole is not limited to the design and modernization of vehicles. Even the most advanced hydrofoil or hovercraft cannot fully realize its potential unless the traffic control system provides the necessary conditions. For example, the introduction of supersonic airliners required the rearrangement of ground facilities. It would be absurd to spend several hours reaching an airport near Moscow and then cross several thousand kilometres to Alma Ata in merely two hours by a supersonic jet. Consequently, the high speeds of aviation imposed strict requirements on ground transportation. Therefore a high-grade highway had to be constructed from the city to the airport, and the passenger services rearranged and comfortable buses provided to transport the passengers to the airport.

Thus an increase in speed of one mode of

transportation entails alterations in diverse areas of human activity and changes people's attitudes. Transportation is one of the factors that influence our way of life most. This can be clearly illustrated by the case of the Baikal-Amur railway. The construction of this line has caused dramatic changes in the lives of those in the surrounding regions. During the construction stage, new townships and towns with new industries appeared there. The line facilitated the transfer of people to previously unpopulated areas and brought new trades for the indigenous population. In the future, new industrial and agricultural areas will grow around the line.

This invigoration the regions around the Baikal-Amur railway have enjoyed awaits the unpopulated and resource-rich areas of the Soviet North, but only if a transportation system capable of efficiently operating in the tundra and permafrost conditions can be developed.

The evolution of transportation has, however, some negative aspects. The improvement of vehicles has a tendency to increase the power of the driving unit. This has a sizeable impact on the environment caused by unburned fuel exhaust, noise and heat.

Supersonic aircraft have their own ecological problems. They can fly at altitudes of 20 km within a certain layer of the atmosphere. At lower altitudes they encounter much more drag, while at higher altitudes there is not enough oxygen for their jet engines. However, exactly these altitudes contain a thin layer of ozone that shields the Earth from the hazardous portion of solar radiation. Aircraft exhaust at these altitud-

es can destroy the ozone blanket, "tears" in which heal slowly. Therefore the extensive introduction of supersonic aircraft along certain routes should be preceded by a careful analysis of the possible consequences.

Ordinary vehicles may also deleteriously affect the environment when operating in new conditions. For instance, wheeled transport in permafrost regions leaves deep tracks in the surface layer of tundra, which will then be unable to support new growth for dozens of years. Iceland moss reappears in these tracks only in twenty years. Therefore if the existing vehicles are not suitable for unusual conditions, other means must be developed.

Thus, mankind has now reached a state when certain technical achievements, including vehicles, must be assessed for their possible impact on the physical environment and on global processes.

The role of transportation in the future of mankind is enormous. Now that we live in the space age we may speak of a new turn of mankind's evolution. It is quite obvious that the settlement of man on other planets is no longer science fiction, but is now a topic facing science and technology. The transfer of man and technology to an extraterrestrial environment is motivated by the objective reasons of the progress of the civilization.

One such reason is the continuous growth of production. A society gross product may be used as an indication of its level of development. The product keeps growing all over the world—the amount of mined resources is increasing, the spe-

ctrum of commodities is expanding, labour productivity is growing, and developing countries are building up their national industries. As a result, the gross product snowballs. One estimate predicts a 200-fold increase in the gross product within the next 40 years, other estimates speak of a 40-fold increase.

We have never had and will never have machines, mechanisms and processes with efficiencies equal to unity because a perpetual motion machine is impossible. An efficiency lower than unity indicates that a process wastes a portion of energy in the form of heat released into the atmosphere and eventually into space.

So long as the Earth's production was insignificant, so were the heat losses. If we look at future production, even the lower long-range estimate of production growth suggests that the amount of released heat will be so large that it may disturb the pattern of the atmospheric processes on its way to space and hence endanger life on our planet. A partial solution to this problem is to boost the emission of heat through a particular window in the atmosphere, but this leaves the entire heat buildup as it was.

Accordingly, mankind has only two ways out: (i) to phase out production capacities, restrain the extraction of resources, constrain the development of developing countries, that is to decelerate the progress of the civilization; or (ii) to transfer the most energy-consuming processes (involving the extraction of mineral resources, metal melting, and the like) beyond the Earth's atmosphere, to other planets, to asteroids, satellites or space stations, and to bring home from

space the finished products, say metal ingots, semiconductors and other materials. Of course, the return of the finished product to the Earth would require the descending apparatus to be decelerated through the atmosphere which is bound to liberate considerable heat. However, this deceleration would take place in the upper layers of the atmosphere, and the heat released will escape into space without overheating it.

The deployment of the production processes beyond the Earth implies that we would live first in the near-planetary and then in the solar space. Therefore the space era has a beginning but no end. Without the utilization of space the development of civilization is impossible. In order to live in the near-Earth space and then in the solar space, a new type of transportation, space tugs, will have to be developed. Today we are on the verge of emerging these vehicles. The first step toward this objective will be to go from single-launch rockets to reusable vehicles or shuttles. This step will cut down the cost of the flight and prepare the conditions necessary for the development of reusable space tugs. Space transportation embodies the most advanced achievements of the current scientific revolution.

The utilization of the solar space and the establishment of living quarters beyond the Earth's atmosphere would call for new relationships among people, excluding violence as a means of solving international conflicts. Consequently, the advance of new transportation is bound to bring about changes in the life of the Earth's population.

What is Better — a Tractor or an Electric Train?

One should introduce more machines everywhere, and implement mechanized technology on as a wide scale as possible.

V I. LENIN

Multiple Requirements for Transportation

Transportation is a major factor in human endeavour, without which the progress of society would be impossible. The multitude of transportation forms has been brought to life by the diverse fields of human activity. It is life that motivates the advent of new vehicles.

Transportation performs many functions. What is better—a tractor or an elecrtic train? A tractor can take goods where no roads exist. An electric train can transfer many people at high speeds without deleteriously affecting the environment. An electric train needs a railway line and an overhead contact wire, both have to be laid in advance. It would be a good thing if the cross-country capability of a tractor could be combined with the speed, seating capacity, and the absence of exhaust gases of an electric train, but is this possible?

It would be difficult, and often impossible, to combine in one vehicle a multitude of desirable features, the more so that the number of features believed desirable increases as the vehicle becomes more advanced.

Suppose we need to lift an object to a certain

height. First we find a solution to this problem, then the idea is realized as a lifting mechanism to perform the task. But to convert this mechanism into a vehicle, it must meet a number of additional constraints. It must be safe and reliable in operation, possess sufficient capacity for the task, and be economically feasible. The conversion of a mechanism, designed to lift goods, into a vehicle is preceded by improvement, engineering development, and modernization.

If after the respective modernization the vehicle can perform both the given task and a whole class of similar jobs, then various modifications are developed so forming a new mode of transportation. In this case the number of requirements that the family must satisfy increases further.

The additional requirements for the familiar passenger lift are a comfortable ride for the passengers who should not be subjected to sharp accelerations and decelerations; a smooth and noiseless travel of the cabin; ventilation and illumination in the cabin; and communication and signal facilities within the cabin.

If the set of specifications cannot be met, then the new vehicle may not be viable. A cross-country capability and vehicle economy are difficult to combine. For example, the cross-country capability of the air cushion vehicle is determined by its hover height above the ground, that is, the height of the air cushion. This operating height is, in turn, proportional to the square of the power expended to create it. Greater power requirements mean a heavier power unit, larger fuel consumption and eventually lower economic ef-

ficiency. Therefore, from the multitude of performance specifications imposed on a vehicle the most important should be selected.

An oil field in this country lay beneath a swamp. To bring people, pipes and equipment to the drill site, a road had to be built. Construction teams filled the swamp by sand from a nearby borrow pit to a depth of 7 m. Road building machines compacted the sand and then it was covered with heavy concrete slabs. The cost of the road exceeded one million roubles per kilometre. This cost indicates the cost which oil people were prepared to pay to get a vehicle capable of crossing the swamps.

An air cushion vehicle could provide such transportation. A vehicle of this type was demonstrated to delegates of the First All-Union ACV Conference which took place in Tyumen in 1972. A prototype of a track-lying vehicle on an air cushion moved over a swampy area at about 40 km h^{-1}. It was not the speed or efficiency that was the major feasibility criterion for this vehicle, but its off-road capability. Even if it crawled slowly and squandered fuel, the vehicle would be appropriate if it could transport goods across an impassable swamp.

Project Feasibility Analysis

If a vehicle has in addition to an off-road capability other attractive features such as speed, efficiency, and payload capacity, then the spectrum of advantages sizeably affects the scope of its use. The operational potential of each vehicle depends on how many requirements it can meet

and at what level it can satisfy them. These requirements may be viewed as the criteria by which a design alternative can be assessed as being able to perform a given task. What are these criteria?

When assessing the capabilities of a vehicle we are above all interested in its speed. A vehicle's speed depends on many factors, such as the resistance to motion, the power developed by its engine, and the structural design of the vehicle. A very important criterion is also that of economy, which grows in significance and is often a decisive one with the evolution of science and engineering. Other feasibility criteria are safety, reliability, off-road capability, payload capacity, throughput for a transport system, comfort, and environmental impact. The impact of transportation on the environment is at present very important and should be carefully assessed for each new option; in future this factor will increase in significance still more.

The set of criteria which a vehicle can meet at a level not previously attained indicates whether or not it will be suitable as a new mode of transportation. Quantitatively a generalized criterion (factor) is often devised as the product of the component criteria devised as performance factors. If a performance factor for the vehicle being developed matches that for the existing vehicle with which it is to compete, then the factor is assumed to be unity. Accordingly, a factor higher than unity means a better performance, while a failure to meet at least one of the requirements yields a zero performance factor, which means that the generalized criterion will be zero.

In the latter case, the vehicle cannot be developed so as to compete with existing ones, to say nothing of it being a new transportation mode.

Let us assess the performance of a variety of transportation mechanisms using the criteria principle we have just devised. When supersonic aircraft were first being developed some of components had to be tested under environmental conditions as close to the operational ones as possible. Due to certain reasons wind tunnels could not simulate flight conditions, so the units to be tested were mounted on rocket propelled bogies. The bogies were accelerated to several times the speed of sound.

High speed was the major and sole objective for these bogies. The expense was immaterial in this case since environmental tests done this way would be less expensive, and more important, safer than if performed in a real flight. The bogie met the requirement. It would be wrong, however, to consider it a new vehicle or even a new mode of transportation, because of its economical performance. Indeed, its operating economy factor, and, consequently, its generalized factor, were close to zero. It is easy to see that this vehicle had virtually zero component factors with regard to environmental impact and comfort. Hence, a rocket bogie can only be a test facility.

This comparable criterion approach is a simple way to analyse the development of vehicles and to determine when and by solving which scientific and engineering problems a toy becomes a new method of transportation.

A promising mode of water transportation in

recent decades has evolved with hydrofoil vessels. They are now widely used in many countries. However, the hydrofoil like many other inventions was not at first accepted, and the creators of these vessels were rarely, if ever, honoured.

A hydrofoil was devised by a Russian citizen, Paul Lambert in 1890. However, the dull and impenetrably arrogant officials of tsarist Russia mocked the idea and refused to grant it a patent. Lambert left Russia in 1891 and patented the craft first in France and then in the United States in 1894. But the technological level of the time was not up to the invention and he died in obscurity. The invention though was not forgotten; Enrico Farlanini built such a ship in Italy in 1905. The theory of a foil in a liquid flow was not sufficiently elaborated at the time and Farlanini failed to obtain a smooth and stable ride. The ship accelerated until its hull was clear of the water, then it fell back, only to take off again. A vessel that jumped like that could not be used as a transportation craft. The newspapers of the time reported the ships in the way they would be a side show or a sport for the daring.

The criteria this jumping vessel failed to meet were those of safety, reliability, and comfort above all, and of course the efficiency criterion was far from perfect.

To be successful the vessel had to be made to glide stably at the design speed with the hull supported above the water by the foils. In 1919 Bell and Boldwin of Canada developed a hydrofoil skimmer. However the stable motion problem for hydrofoils was still far from solved. It

was only after the Second World War that the Central Design Establishment on Hydrofoils in Gorki, on the Volga River finally solved the problem and it is now the source of all the prime modifications of hydrofoils in this country.

Air cushion vehicles (ACVs), or hovercraft, are another challenging form of water transportation. Pressurised air blown by fans of the vehicle is directed underneath the hull. The air cushion thus produced between the bottom and the water surface supports the vessel. This design solves two problems straightaway: (i) the shallow water capability of the craft is improved because now it moves above the water, so shallows are not an obstacle; (ii) the hydraulic drag also drops, especially at high speeds, since the hull is not submerged in water. These vehicles may be propelled by a tractor- or pusher-propeller, jet engine, water jet ejected by a pump, or a submerged marine screw.

An air cushion for ships was first suggested by E. Svedenberg, a Swedish scientist, in 1716. Two man-driven propellers were to blow air underneath a ship that had a bell-shaped vertical profile and an ellipse-shaped horizontal profile. Svedenberg understood, of course, that man power would not be enough to produce an air cushion and hoped that his idea would be realized in the future.

In 1882, a British patent was first granted for an air cushion to the famous Swedish inventor and scientist De Laval who in 1885 constructed the first ship to have an air cushion. The vehicle, however, failed in tests.

In 1895, W. Froude, a British scientist, sug-

gested that the best application of air-film "lubrication" would be for ships which have a circular outline in plan.

In 1897, Cuberstone filed a US patent for a vessel with an air cushion produced by air blown through troughs along the hull.

In 1916, D. Tomamhul, an Austrian engineer, constructed the first ACV with sidewalls or skegs. It was powered by four 88.23 kW (120 HP) engines. Air was blown underneath the ship by a centrifugal fan, while the thrust was produced by submerged propellers.

In 1925, W Casy filed a US patent for an air recirculation system which required a low power fan for the air cushion.

In 1934, the tests were run on the first Soviet ACV which was designed and engineered by V. I. Levkov, Professor of mechanics at the Novocherkassk Polytechnical Institute. Three years later, an improved model weighing 9 tonnes run a measured mile with a record speed of 135 km h^{-1}.

The benefits of the hovercraft are obvious. It does not need costly piers or berths. The vessel can climb sloping banks and descend onto supports, which makes it possible for the passengers and goods to be unloaded. Then the vessel can continue its flight over water.

There are over a million rivers in the Soviet Union, less than ten thousand of which are navigable. Many rivers are not navigable because of shallows, so that hovercraft would be a valuable transportation system. ACVs can operate in both summer and winter since frozen water is

a suitable surface for them. Also, ACVs are not endangered by submerged logs—a scourge for hydrofoils.

ACVs meet all criteria for speed, obstacle clearance, and comfort. How about those for operating economy, safety, and reliability? The craft moves stably over a plane water surface, consuming relatively little energy to propel itself. As soon as rough waters occur, however, the craft must be lifted above the wave crests to ensure stable smooth motion. Greater hover heights require much more energy which is proportional to the square of the hover height. Hence, the power unit must be more powerful. A more powerful engine entails a higher weight and lower economy, that is, the cost-effectiveness of the craft is reduced. Accordingly, the operating economy factor for rough waters will be different from that for still waters.

To cut down the power expended on the air cushion, the air mass flow requirements should be decreased. There are several ways to achieve this goal: preventing the air from escaping by attaching an air curtain around the cushion, confining the cushion within a skirt made from an elastic material, and the use of air recirculation systems in which the worked air from the cushion is again redirected by a system of flaps or fans into the air cushion area before it escapes to the atmosphere.

Heavy seas also create a number of challenges concerning the craft's stability, operational safety, and the reliability of its units and systems. Meeting these challenges is the prime concern of ACV designers and development engineers.

Hence, a change in the operational environment alters the design criteria for a vehicle. The capabilities of a vehicle to meet the design criteria, therefore, govern the potential scope and application areas for this vehicle. To date ACVs are exploited for shore navigation and ferry trips, to transport passengers and goods over a limited sea area, say over the English channel.

Airships—a Proposition for the Future or a Transportation for Today?

A host of publications in recent years have been devoted to dirigibles (airships). Engineers in many countries are now designing and developing them for various uses. Some of the designs are so useful that it seems surprising that they have not yet been commercialised. It would be instructive therefore to assess the potential of airships in terms of the respective criteria.

The main advantage of a dirigible is its ability to transport cumbersome loads to inaccessible or difficult-to-reach locations, in other words, the craft has a high load capacity and good cross-country ability. Since airships can transport the loads relatively quickly, these craft, in terms of the respective criteria, are superior to the other vehicles employed for similar jobs.

By way of example, in contrast to the barges and lighters that are used to move heavy and large structures, an airship does not need a water course and can transport appreciably larger and heavier loads than tracked vehicles and heli-

copters. Besides, it does not need a road like articulated lorry and its operational economy is much higher than that of helicopters. The airship meets most severe criteria for comfort and environmental impact. What remains are the performance factors for operational efficiency, freight throughput, safety, and operational reliability.

The economic side of dirigibles is related to the freight throughput. The construction cost of a dirigible exceeds that of a helicopter, but its operational cost is lower, so that the difference is offset if the payload is significant. Hence, to do a cost-effectiveness analysis for an airship its specific job must be known. That the airship is worth using is beyond doubt—its potential uses are many, and it would be difficult to select an area of human endeavour where an airship would not be useful.

Forestry can use airships to fight fires and insects, and to assist logging in remote inaccessible areas. Power engineering can employ airships for constructing power transmission lines and transporting hydroturbines, electric generators, transformers, and small power stations driven by solar or wind energy, or diesel operated. In the gas and oil industry, they can transport rigs and towers, heavy and unwieldy equipment, lay out long pipes in pipelines, and transfer construction workers' townships along the pipeline. In machine building, they can establish direct links between manufacturing facilities transshipping large items and assemblies. In exploration geology and mining engineering, they can be exploited for surveying and for transporting

geological parties. This listing is only a short portion of the work which an airship can perform.

Now we look at their criteria for safety and operational reliability. In fact, it were safety problems that forced engineers to abandon airships a few decades ago.

The airship is a lighter-than-air vehicle. To provide buoyancy a baloon is filled with a gas lighter than air, say hydrogen or helium. At standard temperature and pressure (STP) 1 m^3 of air weighs 12.67 N, whereas 1 m^3 of hydrogen weighs only 1.08 N. Excluding the weight of the envelope, the buoyancy force of 1 m^3 of hydrogen is $12.67 - 1.08 \approx 11.59$ N. Under the same conditions, 1 m^3 of helium supplies a buoyancy of 9.8 N. The lift of a dirigible therefore grows with volume, and the vehicle only becomes efficient at rather large volumes. For each vehicle, there is a minimal volume of gas needed for it to take off.

The safety of an airship depends on two factors—the vehicle's size and the gas used to fill it. A large craft is very sensitive to weather conditions and to atmospheric eddies, is vulnerable to icing, and is difficult to anchor.

If filled with hydrogen, the airship is dangerous because hydrogen is inflammable. Helium is not inflammable, but is relatively expensive. On the other hand, owing to its design features an airship has a number of advantages that increase its operational safety and reliability. It is independent of faults and failures in the engines and control systems, and instantaneous navigational errors. It can travel for long distances

without time limit and does not need a special airfield to land on.

There is one more factor that may have influenced the fate of the vehicle. The large size of the vehicle makes it an easy target for saboteurs or enemy airplanes in times of war. The unique capabilities of airships make its possible loss still more harmful. This factor is really psychological in nature, nevertheless it is significant and should be taken into account. Moreover, the psychological factor is connected with the catastrophies involving airships in the past and severely restricts their revival. Nevertheless airships' indisputable advantages, backed up by the modern production capabilities and technological achievements, are enabling engineers to construct operational, reliable and economically viable airships. For instance, cheap helium—the safe filling gas—can be obtained as a byproduct of the production of manganese. The first airships in a new generation have now appeared. Forty four years after the explosion aboard the German airship *Hindenburg*, and fifty one years after the crash of another air colossus, the English R-101 airship, a new passenger dirigible, the *Skyship 500*, took off in Great Britain in September 1981 (Fig. 5). It was designed by Roger Mank, a British shipbuilder, and its design philosophy was unlike that of the previous craft. Mank abandoned the rigid frame design to considerably cut down the mass of the craft. Its envelope was filled with helium, a heavier gas than hydrogen but one that was essentially safe. This major difference between the modern dirigible and its predecessors which used hydrogen, is due to the

ability of modern technology to yield helium in the desired quantities and relatively cheaply. *Skyship 500* is only 50 m long, so its pre-flight manouvering can easily be handled by

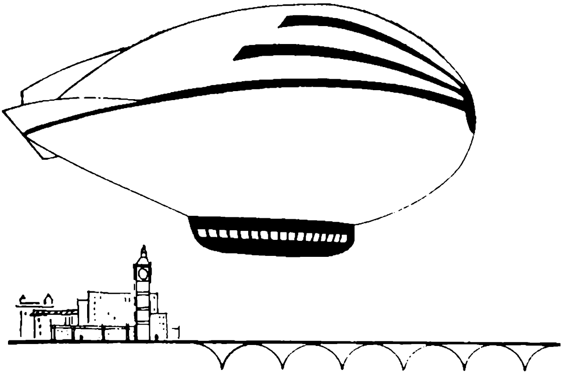


Fig. 5

a few men. The vehicle is propelled by two engines made for the *Porshe 930* sports car, which drive ducted propellers. The vehicle can transport a two-tonne payload at up to 115 km h^{-1} and remain airborne for up to 30 hours.

The dirigible was made of the most advanced materials: the envelope was made from dacrone, the body from plastic reinforced by high-strength Nevlar fibre, and the load bearing members were made from composite materials with honeycomb inner structures.

Skyship 500 made its first official test flight in October 1981. Today there are designs for airships under development that can carry as

many as 200 passengers. The authors of these projects believe that airships will be more profitable than airplanes for routes up to 500 km. According to some estimates, an ariship for 200 passengers will cost a third that of an airplane of the same seating capacity. In addition, the operational costs of an airship will be considerably lower.

But all these benefits are in the future. Airship building firms will be established where craft will be constructed by engineers skilled in the art. At present airships are constructed in many countries either by enthusiasts or by organizations which need them such as the power engineering or oil industry. These efforts are obviously not enough to satisfy public needs.

The Soviet Union built 16 airships between 1920 and 1947. After a break of 35 years, another airship 20 m long and 15.5 m high took off in the Urals on 9 May 1982. It had a cabin and a few pipes hanging from below. On the first flight it was kept on a rope for safety. The flight was completed successfully.

The much disputed vulnerability of airships to the weather and primarily to winds can in many cases be coped with by putting up a wall or two vertical walls at an angle. These provide a safe and cheap airshed. This structure might provide shelter for the vehicle in extreme situations, but it cannot solve the problem for airships that must operate to a time table and in variable weather conditions. Therefore there is a certain interest in tied airships.

The Soviet journal *Izobretatel i ratsionalizator* (Issue 3, 1981) reported a transportation system

developed by V N. Andreichenko, which consists of airships gliding on a short tie along a cable, as shown in Fig. 6. This system involves the concept of aerodynamic unloading of a railway, which was suggested by the author for winged TACVs (the aerodynamic lift exceeding

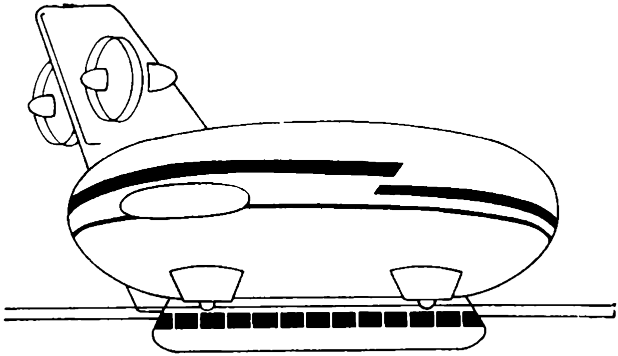


Fig. 6

train weight). In winged trains, aerodynamic lift is due to the wings whereas in Andreichenko's system it comes from the buoyancy of the airship. The tied airship idea ensures the stable operation of the vehicle. Airships will not pollute the air in populated areas because the exhaust from their engines will be distributed in the atmosphere far above the clouds of gases formed by the exhausts from motor cars. The system is also invulnerable to collisions. Airships are not impeded by highways or streets. This limitless motion enables a tied airship to develop a speed comparable to express trains or even airplanes,

The inventor has estimated that a kilometre of this air transportation system will cost less than a kilometre of a high-voltage power line, i.e., about 16 thousand rubles. Each kilometre of tramway, by comparison, costs 130 thousand rubles, and a kilometre of highway 150 thousand rubles. Of course a tram is far cheaper than an airship, however, the seating capacity of an airship is closer to that of a commuter train than that of a tram.

Andreichenko believes that his air transportation system could link towns and industrial areas far from the railway networks. At any rate, it would be a simpler and cheaper enterprise to route such a system through swamps, taiga, or desert areas than to construct a highway or a railway there. As a result, the system has a good cross-country ability.

Another possibility is worth noting. There should in principle be no difficulty to supply the electric motors of a tied airship with energy. This would free the vehicle of the need to carry fuel nor would it pollute the atmosphere with the exhaust gases.

Thus, technological achievements and the ingenuity of an inventor make it possible to combine in one vehicle the properties of different modes of transportation, such as the off-road vehicle of high cross-country capability and the electric commuter train of high seating capacity.

Cushion ... but of What Type?

> To be surprised needs but a minute, to make something surprising needs years.
>
> C. A. HELVETIUS

When the Wheel Fails to Do the Job

Is it possible to predict the appearance of a qualitatively new method of transportation? Yes, it is. We can do so because of the laws governing the development of transportation.

In any mode of transportation, there is a drive for higher speed, which, accordingly, must increase. Every technological achievement is used to achieve this purpose. If the maximum speed of a type of vehicle is not improved for a long time, then the transportation is not continuously developed and hence the scope for modernizing this type of vehicle is exhausted and qualitative change is to be expected.

Some types of vehicle have higher speeds than others, but each type has a characteristic range of speed. According to the dialectics of transportation development, there cannot be a large gap in the speed spectrum between adjacent modes of transportation. If a gap occurs, then a qualitatively new mode of transportation whose speed range would fill the gap would be expected.

By the mid-1950s, the maximum speed of airplanes exceeded $500\,\mathrm{km\,h^{-1}}$ while the best express trains could only manage $120\text{-}160\,\mathrm{km\,h^{-1}}$.

The gap in speed kept widening since in the next years train speeds were likely to grow to 180-200 km h^{-1}, while those of airplanes to 650-800 km h^{-1}. As a result, there appeared a transportation speed gap from 180-200 to 600-650 km h^{-1}.

This situation could not but stimulate new ideas. Qualitative changes have taken place in water transportation. Hydrofoils are being constructed which double over-water speeds. But these speeds are beyond the speed gap.

There is feverish improvement in the design of public and personal automobiles. Highways are being constructed to accommodate comfortable long-distance buses and fast cars. A speed of 120-160 km h^{-1} on a freeway is no longer a wonder. Further increases of speed on highways was curtailed by the energy crisis which sent fuel costs through the roof. The operating economy criterion had its say.

The process of technological advancement has also touched railway transportation. Steam locomotives gave way to diesel and electric locomotives. The electrification of the railways was carried out extensively. All these measures failed, however, to produce a sizeable increase in train speed. It should be recognized that in the mid-50s the railways were facing a shortage of passengers. No one wanted to waste a week on a trip from Moscow to Khabarovsk in the Soviet Far East when an airplane could cover the distance in 8-10 hours. This attitude affected small-distance trips as well. Here passengers preferred comfortable buses or hydrofoils travelling at 60 km h^{-1} to ordinary trains. Hence, the railways

faced a speed crisis, more severe than that faced by any other mode of transportation.

In 1964, in France, a world record for railway speed, 331 km h^{-1}, was set up. However, the railway line had to be reinforced after this record run. It was the railway track that had set back the growth of train speeds. High speeds create such intense dynamic loads on the track that it loses its strength and may fail. Therefore the main task faced by railway authorities was to lay stronger track: more massive rails were installed, and wooden sleepers were replaced by reinforced concrete ties. Today most railway sections have been given the heavier railway track. When this sort of track was laid all along the line from Moscow to Leningrad, train speeds could be increased and a Soviet speed record of 200 km h^{-1} was set for trains.

The heavier rails will solve future problems. As the operating speed increases so does the dynamic load on the track, and therefore even this track will eventually not be strong enough. To compound the problem, at high speeds the railway wheel begins slipping against the rail, and the wheel can no longer satisfactorily transfer the traction force.

In 1967, Japanese train manufacturers conducted maximum speed tests for a 12-car superexpress on the Tokaido line. The speed was found to be 370 km h^{-1}. A further increase in the force applied to the wheel failed to raise speed but instead caused the wheels to slip on the rail.

Existing railway lines could not take this operational speed, primarily for technological and economic reasons. For a 200 km h^{-1} operating

speed the cost of the mechanical components of the wagons, rail track, and automatic control systems starts to increase rapidly. The problem is compounded by the fact that increasing train weight improves adhesion between the rail and the wheel but in turn extra weight increases the dynamic load on the system, an extremely dangerous situation at high speeds.

It was suggested that the wheel should be released from its role of a traction transmitting component by mounting a rocket engine above the train, as shown in Fig. 7. In this configuration, the wheels merely support the train on the rails.

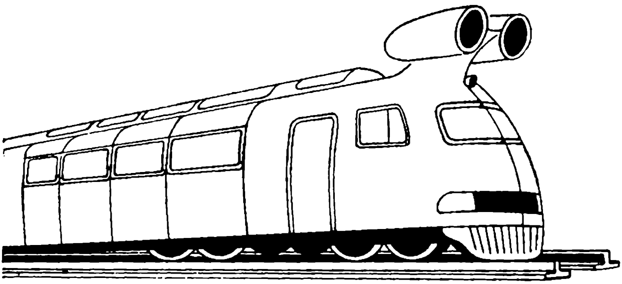


Fig. 7

Let us look at the potentials of this train from the comparable criteria viewpoint. The train should operate at about 300 km h^{-1}. This speed would not eliminate the speed gap, yet 300 km h^{-1} for railway would be a large success, and this speed performance would be far superior to that of conventional trains.

A train powered by rocket engines was designed for use on existing railways. Therefore, its cost-effectiveness criterion seemed to be held to a desired level. Indeed, no further investment in new railway lines was anticipated. However, these railway lines are used by ordinary passenger and freight trains which operate at the much slower speeds. The speed mismatch between jet-propelled and ordinary trains would cause a situation when one rocket train would destroy the timetable for a dozen conventional trains which would be compelled to halt in sidings until the express has passed. It is quite obvious that this waiting would be costly. Accordingly, the jet-propelled train fails to meet the operating economy criterion.

Assessing this train from the safety criterion viewpoint, we must not overlook the possible dynamic shock that would occur between two such trains approaching each other in adjacent tracks, their combined speed being twice 300 km h^{-1}. There are many other problems. But here one operating economy criterion is enough to disqualify this train as promising method for using the existing operational environment.

Estimating the utility of a jet-propelled train in terms of relative performance factors indicates that it cannot be considered the new mode of transportation as the press has dubbed it recently. This concept was not an attempt to solve the transportation problem, but rather an attempt to improve an existing type of vehicle. The aim was to raise the speed of the vehicle by removing the obstacle to higher speeds, but due attention had not been given to the effect of such an impro-

vement on the whole railway transportation system.

The efforts to improve the speed of trains continued. In Japan, a 250 km h^{-1} high-speed express has come into operation over the Tokio-Osaka section which is 450 km in length. The railway track is laid over on a trestle structure and has no crossings. A sizeable effort is underway in France to develop a superexpress. A bullet-train running at 377 km h^{-1} is currently being tested. This train will whisk passengers from Paris to Lyons in half the time for ordinary trains. The engineering development of such trains must overcome a number of challenges associated with the wheel-rail system.

The wheel, one of man's greatest inventions, has become an obstacle to higher speeds. How about replacing the wheel with an air cushion?

We have already mentioned that the first person to come up with the idea of an air cushion craft was E. Svedenberg, a Swedish scientist, in 1716. In 1853, a Russian engineer Ivanov suggested that an air layer under the bottom of a ship would decrease the resistance of the water to the ship's motion. The vehicle, called a trimaran floater, was to be propelled by the air jet escaping from the rear end of the ship's base. The idea of air jets under the hull was taken up by S. Rossel in the 1860s and V. Froude in the 1870s. However, all these ideas and developments did not evolve into a form of transportation.

In 1927, K. E. Tsiolkovsky published *Aerodynamic Drag and the Express Train* in which he gave an engineering definition and the design principles for a vehicle that would move on an

air cushion over a special track. The thrust would be produced by an air jet exhausting from under the train and pointing backwards. The paper contains formulae for determining the necessary pressure in the cushion, its operating height, air rate, fan power, and some other parameters. These expressions form a theoretical foundation for any modern analysis of such vehicles. Tsiolkovsky believed the vehicle would fly over ravines, hills, and rivers along a ballistic trajectory. In fact he suggested that a shell-like train could accelerate along the track before it takes off.

For all its worth, the train Tsiolkovsky described cannot be used as a transportation means. Free flight for a shell-train would require high speeds and, consequently, high energy inputs to overcome the resistance to motion. Its propulsion over the track when the train would be supported by the air cushion would also require considerable energy. Accordingly, its relative operating economy factor is unsatisfactory. The train also fails to meet the criterion for safety, as it remains unclear how the train would land after its ballistic flight. Nonetheless the idea of replacement of the wheel by an air cushion was revolutionary. This train is likely to have been envisaged by its author as a possible starting facility for the jet-propelled boosters he developed at that time for space exploration.

Thus, by the mid-1950s, a transportation speed gap had taken shape, between the fastest ground vehicles and jet aircraft, that had to be filled. It was evident that the mechanical contact between the vehicle and its supporting surface must be eliminated.

In 1959, the British engineer C. Cockerell tested an air cushion vehicle, called *Hovercraft*. The vehicle embodied the same basic developments as those contained in a craft constructed and tested by V. I. Levkov, Professor at the Novocherkassk Polytechnical Institute, in the early 1930s. Unfortunately, the new vehicle failed at that time to be duly appreciated.

In 1955, in Khlebnikovo near Moscow, G. Turkin, a 20-year old student of the Moscow Oil Institute, tested a model of the motor car with an air cushion. In the first trials the 4-kg model lifted 12-16 kg of payload. Turkin built a full-scale vehicle. The design was improved during the trials. For example, when the shafts coupling the motors with the fans twisted under load, Turkin removed them and mounted the propellers directly on the shafts of the motors. The vehicle hovered above the bank of the Klyazma reservoir. The inventor immediately decided to test it over the water. When the vehicle moved away from the silty bank, one of the motors stalled. Turkin got out of the vehicle only to fall dead from a heart attack.

Neither water-going vessels nor automobiles supported on an air cushion, however, were capable of speeds of hundreds of kilometres per hour; they do not have enough power. The principal virtue of these vehicles is their high cross-country ability. To ensure this the vehicle must produce an air cushion with a sufficient operating height. For an over-water ACV, the hover height depends on the height of the waves; for a land vehicle, on the height of the obstacles to be cleared. Recall that the higher the air cushion

the greater the power needed to generate it, which increases in a square proportion. The drag also grows as the square of the height. Therefore, hovercraft require such quantities of energy to travel at speed that these vehicles become uneconomical.

A Winged Train on an Air Cushion

When used on a track, the air cushion supporting a train may be made considerably thinner than the cushion of an unguided ACV. For a smooth surface track which can be easily produced with modern technology, the cushion need be only a few millimetres thick. This air cushion acts as an air-film lubrication between the bearing surface of the train, the chassis, and the surface of the track. A thin air-lubrication layer can be produced with much lower powers. The remaining power may be used for propulsion.

If wings are installed on the train they will provide ever more lift as the train speed increases, and the air cushion will be progressively relieved from loading, but the lighter the train, the lower the power requirements of the air cushion. This results in an energetically competitive system, which, consequently, is good from the operating economy viewpoint. At low speeds the wing performs inefficiently, and most of the power is expended on the air cushion. As the speed grows, so does the drag, but the efficiency of the wings increases, lifting the train, so the train load on the air cushion decreases. The available power can then be directed to coping with the drag and rising the train speed.

Thus, when the train speed rises up to a certain level, as determined by the growing drag, the operating economy of the train in fact improves. At speeds exceeding 400 km h^{-1} the air cushion can be created without fans, simply by the dynamic head of the oncoming air ducted between the bearing surfaces of the train chassis and the track, producing the so-called ram-wing or screen effect. This effect further improves the train's economy at high speeds.

A winged air cushion train (TACV) will not be like ordinary trains in design or appearance. First, there can be no chain of carriages, for at speeds above 400 km h^{-1}, the behaviour of couplings becomes unpredictable. From the outside the train will look more like the fuselage of a large passenger aircraft. The wings of the train will not be like those of an airplane. The train moves close to the Earth's surface, and thus the wing span need not be as large as that of an airplane; the wings should be spread along the hull or above the train for better aerodynamic performance.

The absence of wheels means that two rails can be replaced by a monorail that provides a sufficient supporting surface. No wheels means no dynamic loading on the rail. Therefore the monorail can be made of concrete rather than expensive metal. The absence of wheels also removes the speed limitations intrinsic in ordinary trains.

The high speeds of TACVs will necessitate that they be isolated from other vehicles and pedestrians. This goal can be achieved by placing the monorail on a trestle a few metres above the

ground. A trestled track is worth consideration not only on safety grounds but from the viewpoint of economy as well, especially if the track is to be routed through impassable areas. In swampy areas, permafrost regions, and some other terrains, a viaduct is preferable even for highways.

Winged TACVs can be propelled by turbojet engines which have good performance capabilities over the speed range from 450 to 600 km h^{-1}. Even better performances can be achieved using by-pass turbofan engines which are equal in performance to turboprop engines and are much less noisy.

A jet engine can create additional lift by directing the gas flow ejected from the nozzle to the trough. According to Bernoulli's equation, the pressure and velocity of a fluid vary in inverse proportion: the higher the velocity, the lower the pressure. Accordingly, a pressure difference will occur between the engine jet flowing through the trough and the surrounding air. This pressure drop will yield additional lift. This lift will be the highest when the train is at a standstill, and will decline as the train's speed builds up because of decreasing speed difference between the jet flow and the oncoming air flow.

Because the train's chassis is close to the track surface, a linear induction motor (LIM) seems to be an attractive proposition for propelling the train. What are the main features of a linear induction motor? If the stator winding of an induction motor is "unrolled" along the track, the rotor is installed in the train and an electric current is fed, a magnetic field occurs between the

rotor and the stator, which will drive the train along the track. The small gap between the train and the track surfaces ensures that the power losses be low. LIMs are silent in operation and ecologically agreeable. However, they have low operating economies at high speeds, which prevents them from being used widely.

Let us look at the technical and economic feasibilities of a winged TACV travelling over a trestled monorail.

As far as speed is concerned, a winged TACV will excel every other mode of transportation save for aviation. However, despite this lower speed a passenger travelling some 3000-3500 km will arrive earlier by train than by airplane. This is because an airline passenger has to spend extra time to reach the airport. Moreover, modern jet planes require airports farther from city centres, so the development of aviation will only increase the city-to-airport journey time.

What is the main trend in the development of aviation? The larger the airplane, the more economical it is. Yet large aircraft need long runways and these have to be constructed farther away from cities. Often the flight itself takes less time than the journey from the city to the airport and from the destination airport to the destination. A TACV route may go through the city centre. Therefore, as far as journey time is concerned, TACVs look more attractive than their competitors.

Safety aspects of transportation pose challenging problems in the modern world. Each year about 55 million accidents occur throughout the world. Virtually one driver in nine is

either wounded or killed in a road accident. The death rate due to motor car accidents ranks third, behind those due to coronary diseases and cancer.

A winged TACV would travel faster than a motor car, therefore, even at the development stage, engineers must establish measures to ensure its operational safety.

The intrinsic safety that a winged train offers in operation is primarily due to two factors: the absence of mechanical contact between the train and the supporting surface, and the consistent coupling of the train with the trestled track. The absence of mechanical contact is due to the air cushion, whereas the train-track coupling due to the train chassis-monorail design. A number of chassis-track systems have been suggested. Which design is chosen depends on many factors, the major one being whether or not the aerodynamic lift at the design speed exceeds the train weight.

If the train's weight exceeds the aerodynamic lift, then the chassis must be configured to embrace the monorail from above and on either side (see Fig. 4). Compressed air is driven into the narrow slot between the planes of the chassis and the track. This configuration prevents the train from leaving the track. Any lateral displacement, say due to wind, will cause a side gap between the chassis and the track to decrease. This will increase the pressure in the gap and an opposing reaction force will be set up. A similar effect will be produced on the train negotiating curves. Hence, in this situation the chassis-track system behaves like one with feedback, that is it is a self-regulating system.

The self-regulation principle is also useful for ensuring stability of motion of the train relative to the track. Stability is of immense importance for safety, economical operation of the power unit, and comfortable passenger conditions.

The train is suspended over the track both in motion and when at a standstill. In this state it is acted upon simultaneously by the aerodynamic lift, its own weight, and traction resistance forces, all of which vary in motion. The weight of the train decreases as fuel is expended. The aerodynamic lift and drag are functions of travel speed, density of ambient air, wind speed, and a number of other variables. Variations in the resistance forces are offset by the propulsive thrust of the power unit. Variations in the aerodynamic lift and the train weight are compensated by the air cushion which acts as a shock absorber. This system becomes unstable when the aerodynamic lift equals the train weight. Therefore provisions must be made to avoid this situation.

When the aerodynamic lift consistently exceeds the train weight, a stable ride can be achieved, with a different configuration of the chassis-track system (see Fig. 3). This configuration produces upward forces applied to the trestled track structure.

Coupling the train to the track has safety consequences. The train is always tied to the track unlike an airplane, and it should be recalled that around 80% of all airplane accidents occur during take-off and landing.

Collision between trains and other vehicles or pedestrians can be avoided by elevating the track

above the ground. The trestle also eliminates problems of crossings, essential in densely populated areas. Special junctions to reroute wheelless trains are also designed.

The trains may be braked in several different ways. (i) The propulsion direction may be reversed by redirecting the ejected flow in the jet engines, or altering the position of the blades in the propellers of turboprop engines. (ii) The aerodynamic drag may be increased by enlarging the cross-sectional area of the train; airplanes do this by deploying braking flaps or drag parachutes. (iii) Braking shoes can be forced into the small gap between the train chassis and the track. For better performance, these shoes should have special coatings.

To prevent the monorail from becoming clogged by sand or debris it can be given a suitable profile. For example, the upper bearing surfaces can be made sloped so as to allow rain and snow to run off and prevent icing in winter. To cope with icing up the high temperature of the jet engine gases can be utilized.

The railway system in the USSR handles the largest throughput of passengers and goods. Winged TACVs can also be configured for large capacity. An ordinary train has a higher payload capacity than an air cushion train, but the latter moves faster, which is essential for track throughput. A considerable increase in railway throughput can be achieved by automatic dispatch systems which reduce time headway between trains to a minimum and monitor train operation for safety. The automatic dispatch system introduced in the Moscow underground

system shortened the time between trains to 32 seconds.

In a transportation system with winged trains, an automatic control system will choose the optimal speeds of and time headways between trains, will control the operation of the train systems and monitor their performance, will control the track's condition, including the state of the monorail, trestle and supports, and will operate emergency braking facilities if needed, to name a few functions. Also, TACVs are weather-proof —a favourable feature for the throughput.

It is assumed that TACVs will be mainly exploited for passenger transit. However, in special cases, they may be used to transport premium goods which are moved by air freight today, or provide a carry route for unwieldy loads.

Thus, winged trains can transport a large number of passengers and relatively light commodities in all weather conditions. Therefore, viewed in general from the throughput criterion angle, they seem to meet the requirements of a new form of transportation, moreover, they are capable of even better performance than, say, airplanes.

As with any other new vehicle, the potential of winged trains should be assessed from the cost efficiency viewpoint. This may be done, for example, in terms of the payoff period for a selected section of a line with a given throughput. We shall not consider all the topics involved in a winged train economy, but confine ourselves to the more important factors.

The efficiency of any form of transportation is substantially dependent on how much power it

requires. In wheelless trains, power must be expended for propulsion and for suspending trains above the track, i.e. for the production of an air cushion.

The first of these power requirements depends on the resistance to motion and is proportional to the square of the speed. Therefore it maximises at the highest speed. Because the speed of such a train grows as high as 500 km h^{-1} or more, the power needed to overcome the drag at these speeds is so high that when added by the power drawn for the air cushion the economic viability of the entire system becomes questionable. Exactly this argument was put forth by the opponents of these trains in 1960. They overlooked or did not want to consider the screen (ram air) effect and refused to look at the idea of using wings to reduce power requirements owing to cushion unloading. Moreover, they argued that the wings would only offer additional resistance and make the train heavier.

A wing is indeed inefficient at low speeds. In this case, a sufficiently large lift may be produced by large-area planes, but these increase the drag and weight. The lift of a wing increases as the square of the speed. Therefore, an outstanding feature of winged TACVs is that their economic performance improves at high speeds. Moreover, at high speeds, the air cushion may be assisted by the dynamic head of the oncoming ram air, which improves the train efficiency still more.

Automobile transportation and railways need roads or tracks which are fairly expensive facilities. This need is because of the high dynamic

loads exerted by automobiles on highways and heavy trains on rails. The cost of a road largely depends on the terrain across which it is routed. Much of the overall cost of a highway or railway is taken up by bridges which cost more the higher the loads they are to withstand.

An elevated track for winged trains offers a number of advantages over highways and particularly over railways. It no longer needs a continuous road bed because each trestle rests on supports that are a considerable distance apart. The trestle sections and track can be manufactured industrially and only assembled on site. Since dynamic shock loads are not involved, the track and trestle can be made of a relatively cheap and available concrete. As it is to operate with dynamically unloaded winged trains, the track will mainly perform as a guideway. Therefore, its strength margin may be considerably smaller than that of railways, while the width of both the monorail and trestle depends on the size of the train carriage. As a result, the whole structure is rather light. This fact facilitates the erection of supports and the assembly of the trestle and track, reducing the construction costs. Per kilometre, the cost of a trestled track for a winged TACV is far smaller than that of a highway or railway.

These features of TACVs result in a very light, reliable and cost-agreeable structure. The train is free from the shock loads normally incurred by moving wheels. If a linear induction motor is used for propulsion, the electric energy to feed it can be picked up from an overhead line, so there will be no need for a fuel store in

the train. If a combustion engine, say a jet, is used for propulsion, it can be refuelled at intermediate stations without problem. Consequently, fuel tanks will not take much room. Nor will the usually bulky wheeled carriage. The train may have light wheels intended to move it away from the track for maintenance or repair work. These wheels occupy only a small amount of room on the vehicle and can be made retractable as in aircraft. All these features contribute to an economical train concept.

A winged TACV flying along a monorail has a high operating economy parameter because of the small height of the air cushion, the high cruising speed, the aerodynamic unloading of the air cushion and the track, the absence of shock loads, the light structure of the train, and the lightness of the trestle-track system.

The relative convenience parameter for these trains is better than for the other recent modes of transportation. The convenience of winged trains is due to the high speeds; also they can bring their passengers directly into populated area, they are independent of weather, and are safe in operation.

Winged TACVs are able to solve efficiently the problem of cross-country transportation. The trestle may be routed over impassable swamps or through permafrost regions, being supported where needed on piled supports. An analysis indicates that the 12-m long piles employed for the construction of multistorey buildings in swampy areas will be adequate. The trestle may support other communication lines too. Taking into account the speed, throughput, and cost efficiency

of winged trains, TACVs may be recognized second to none for penetrating and commercializing remote and undeveloped regions, for example northern regions of this country. Moreover, trains moving on trestles constructed above tundra, affect the soil and plant cover far less than caterpillar or wheeled vehicles.

In terms of all the performance parameters considered, winged TACVs have higher ratings than the existing vehicles involved in the comparison.

Today many countries have constructed, or are developing various types of air supported trains. In one Soviet textbook these vehicles are classified according to the pressure in the air cushion as those with

(1) low-pressure cushions, the air-escape gap being of the order of tens of millimetres;

(2) high-pressure cushions, the air-escape gap being of the order of one millimetre;

(3) suction suspension (inverse air cushion).

This classification is not satisfactory because neither cushion pressure nor air-escape gap is a defining parameter for these vehicles. The pressure in the cushion depends on the vehicle's weight. This weight, however, is not constant in motion and depends on the aerodynamic lift generated by the wings, which grows with the train's speed. It is possible that a heavy train used at high speeds will operate with a lower pressure cushion than a lighter but slower train.

The operational speed of these trains will be limited, on the one hand, by the aerodynamic drag which is proportional to the square of the speed, and, on the other hand, by the scheduled

stops. On a short section, a train just does not have enough time to accelerate to a high speed.

In *The Train with Air Lubrication and Aerodynamic Unloading of the Track. Design Fundamentals*, the author has considered a winged TACV with a seating capacity of 180 passengers, an initial mass of 40 t, and an air cushion height of 8 mm. The train is propelled by two turbo engines, and has wings to provide 80% unloading for the track.

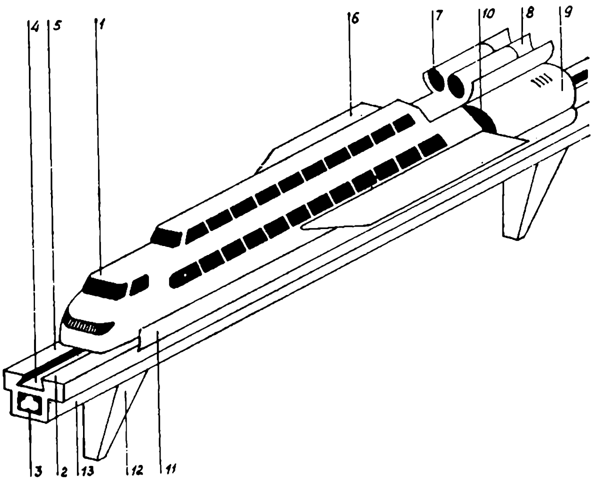


Fig. 8

Figure 8 shows an artist's impression of a winged TACV. The train includes a passenger compartment (1), a sledge (11), wings (6), jet propulsion engines (7), a fan plant (9) which

receives air through an intake (10), and troughs (8) to create an additional lift using the jets from the thrust engines. The passenger compartment is in two layers. The cargo bay is at the bottom of the train for stability.

The train has two modules, the hull section with wings and passenger compartment, and the motor section with the propulsion engines and fan unit. This train configuration makes it technologically reasonable since the modules may be fabricated in a special factory, the respective units being produced in parallel.

The track (5) is mounted on a trestle (13) elevated over the ground by supports (12). It has two smooth supporting surfaces (2) which bear the train via the air cushion, and a service trough (4).

Figure 3 shows the end view of the train and the track when the train is rolling on the pneumatic wheels released in the trough. The wheels can be deployed at stations, and when transferring the train from the main track onto service tracks for maintenance or repair. In motion they are withdrawn into the hull in much the same way as an aircraft's undercarriage. The smooth supporting surfaces of the track are inclined (see Fig. 4) to facilitate runoff and debris removal.

The carriage shown in Fig. 3 has two supporting surfaces—upper and lower. This train-track coupling configuration allows for the air cushion to be operated at the upper and lower surfaces of the track. The "lower" portion of the air cushion is needed whenever the aerodynamic lift of the train, which is a function of train design and travel speed, exceeds the train weight. We

recall that the situation when the total lift force exactly balances the train's weight is prone to be unstable and the vehicle becomes sensitive to any disturbance that may upset the balance.

When the vehicle uses the lower surface of the track for support, the air to this portion of the cushion may be supplied by forcing it from above over the track perimeter through a narrow slit. This design is similar to that used in some upper-cushion configurations, aids in air savings, and forces the air flowing through the slit to act as a curtain between the chassis and the track. A large portion of the air forming the upper cushion may be forced through this slit.

An analysis of this train configuration indicates that at 600 km h^{-1} the wings allow the power to be cut by 975 kW (1325 HP) which is 17 times the power due to the presence of the wings.

The track may also be made to accommodate electric cables, communications lines, and other services (3).

To keep the aerodynamic unloading constant, the plane area of the wings must be changed in accordance with the operating speed. We should also not overlook that the lift due to the air cushion also varies with the speed.

Increasing the speed means that the oncoming air pushes out the air cushion. As a result, the height of the cushion and its supporting force decrease. The aerodynamic head also creates an additional lift which becomes predominant at high speeds and is able completely to replace the air cushion. The effect of both factors needs a separate analysis for each configuration of TACVs being developed.

In the aforementioned publication, the author has presented a hydrodynamic analysis of the winged TACV and considered various aspects of its design and operation, and also the problems connected with the selection of traction engines, stability, braking, automatic control, and the like. Various trestle configurations for the track are covered. A cost-effectiveness analysis is outlined for a 650-km long one-way section of the monorail line designed for an average operating speed of 430 km h^{-1} and a daily traffic of 32 trains.

According to the analysis, the project will be amortized in 3.3 years. If in addition the trestle structure is used for communications cables, the amortization period will be reduced to 3.19 years. For comparison, the amortization period for conventional vehicles normally runs at 7-11 years.

To reduce the noise a linear induction motor can be used for traction. It will be noted that noise emission and engine exhaust were factors that set TACVs at one level with existing vehicles with respect to pollution. Accordingly, the ecological impact is the weakest point for this class of trains. Indeed, the noise of the train engines and fans, the combustion products, and the heat from the power units are all subject to environmental control, especially in populated areas.

The environmental situation improves when the train uses a linear induction motor for propulsion, but there remains the noise of the fans pressurising the air cushion, a major ingredient in the vehicle's noise-pollution spectrum. This drawback is eliminated in TACVs with magnetic levitation. It was the noiseless operation of the train that had first aroused its inventor's liking.

Trains with Magnetic Suspension

A train with magnetic suspension, or levitation, (magnetrain or maglev systems) is to solve the same problems as its air supported counterpart. namely, how to efficiently counteract the force of gravity without using wheels and which traction engine will be best for the purpose. The mode of suspension and the type of traction engine are the fundamentals in the development, engineering, and construction of wheelless expresses in general, and vehicles with magnetic levitation in particular.

The major advantage of maglevtrains is their low level of environmental pollution: they are silent, and produce no exhaust. Therefore it would be illogical to use jet engines or motors with propellers to move them. Accordingly, the motors developed for these trains produce a tractive force as the result of interaction of magnetic and electric fields. The forces of this type can also be used to suspend the train above the rail track.

This interaction occurs in a.c. and d.c. electric motors. A direct-current electric machine relies on the phenomenon of electromagnetic induction discovered by M. Faraday in 1841. An alternating electromotive force (e.m.f.) is induced at the ends of a wire loop rotated in a constant magnetic field. A slip-ring system converts this e.m.f. into a constant voltage (Fig. 9). The ends of the wire loop (3) are connected to the slip half-rings (2) from which the graphite brushes (1) convey the current into an external circuit (4).

A d.c. electric motor operates in agreement with Ampère's law, which states that a magnetic field imposes a force on a conductor through

which a current is flowing. Consequently, if a conductor formed into a loop is immersed inside the field of a permanent magnet and a current is passed through the wire, the induced force will cause the loop to rotate. The first practically useful d.c. electric motor was built by the Russian electric engineer B. S. Jakobi in 1842.

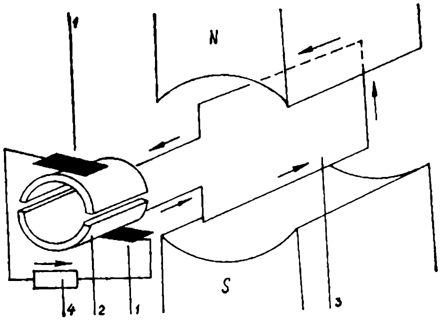


Fig. 9

At first, electric motors were made with permament magnets, then electromagnets appeared.

The active elements of a modern d.c. electric motor include a stator and a rotor (armature) windings, a magnetic core, and a slip-ring assembly. The stator magnetic core has main and commutating poles. The main poles carry the field winding creating the main magnetic field. The slip-ring and brush assembly complicates the motor technology, impairs the system's durability, and is expensive to maintain. Moreover, the assembly limits the rotation speed of d.c. motors to

50-52 m s^{-1}. D.C. motors, however, can provide continuous and economical speed variation over a wide range. Therefore they have become widely used on railway locomotives and other electrically driven vehicles.

This motor may also be used for propulsion in high-speed trains with magnetic levitation provided it is made into a linear motor extended along the track. The application of a d.c. commutator motor to wheelless expresses inflicts certain limitations due to the collector assembly, which is expensive to manufacture and maintain and which, being a mechanical commutator, limits the possible speed to 110-140 m s^{-1}.

The potential of linear d.c. motors widens appreciably if the commutation of the armature windings can be done automatically according to the position of the inductor poles. This sort of motor is called an autosynchronous motor.

Today there is an extensive development effort in this country and abroad to harness the electrodynamic principle for propulsion. Both induction and synchronous electric motors are already known which use this principle. In induction motors, the magnetic field of the a.c. current flowing in the stator windings interacts with the electric current induced in the rotor windings.

This principle was used in induction electric machines after 1888, when G. Ferraris, an Italian physicist, and N. Tesla, a Serbian engineer, independently discovered that a rotating magnetic field could be produced by superimposing two or more alternating magnetic fields of the same frequency but shifted in phase.

A three-phase current fed into the stator wind-

ings produces a travelling-wave magnetic field which interacts with the current induced in the rotor windings to produce a torque which rotates the rotor in the same direction as the rotating field. The speed to which the rotor is accelerated is somewhat less than that of the stator field, that is, the rotor lags behind the stator field. The rotor's slip speed depends on the travelling speed of the stator's magnetic field which in turn is governed by the frequency of the feed current and the number of pole pairs.

There are two basic designs of induction motor, those with a slip-ring rotor and those with short-circuited squirrel-cage rotor windings. When a squirrel-cage induction motor starts up, it draws a starting current which exceeds its nominal value by 4 to 7 times. To lower this current, the motor is switched at a lower voltage and after start-up the rotor winding is short-circuited. The air gap between the stator and rotor should be made as narrow as possible in this type of motor.

The induction principle may be harnessed to drive a wheelless train. A stator (primary) fed by a three-phase alternating current is placed aboard the train while the rotor (secondary) is unrolled along the track. The traction force that occurs between the magnetic field of the stator and the current induced in the rotor causes the flat primary and the train to move over the flat secondary. This arrangement is called a linear induction motor (LIM).

The linear induction motor has a number of advantages for wheelless trains. It is not constrained by speed limits for it contains no rotat-

ing parts that may be torn off by centrifugal forces at high speeds, and consequently no vibration occurs. Besides, rotating parts are subject to rapid wear. A train with such a motor has a good dynamic performance. The train is rather light, so it can accelerate and decelerate rapidly, and the braking energy can be recuperated into electric energy.

Numerous LIM designs are already in existence. In one of them the stator is unrolled along the track (the active member) while the rotor (the passive member) made as an aluminium strip (reaction rail) is mounted on the vehicle. As a result, the vehicle becomes lighter because it no longer carries a heavy stator, whose mass amounts to a quarter of the train mass. Also the problem of electric energy supply to the vehicle when it moves at high speeds is eliminated. However, the cost of the active section extended for the whole track length is so high that this configuration being prohibitively expensive is not considered.

Another conceptual configuration has two stators placed facing each other in the vehicle, each 30-40 mm from a vertical aluminium reaction rail mounted on the track. This is the double-sided LIM with vertical reaction rail and stators. This design complicates the design of track junctions. The problem can easily be solved by using a one-sided LIM which has a single stator installed horizontally on the vehicle while the aluminium strip is again part of the track. To improve the permeance of this arrangement, the aluminium strip can be placed on a steel core to produce what has come to be known as the sandwich

configuration. But the tractive force of a one-sided LIM is half that of the double-sided configuration, other conditions being equal.

With a LIM propulsion system the track will not be heated, since when the train is moving rapidly the track section where the stator's magnetic field interacts with the rotor current does not have enough time to heat up. But the stator is heated by Joule heat. Stator heating is one of the severest problems. Its solution is being sought through the use of superconducting materials.

Superconductivity discovered early this century and theoretically explained 25 years later is characterized by the absence of resistance to electric current and, hence, Joule losses. This phenomenon for ordinary metals occurs when they are at temperatures close to absolute zero (zero Kelvin or $-273°C$).

Electric current injected into a superconducting winding of an electromagnet will circulate there for a long time without encountering any resistance. In one experiment, for example, a 10^6 A current was passed through superconducting magnets in the form of 1.2×0.6 m coils immersed in liquid helium. The current decayed as slowly as 1% a day.

Liquid helium is expensive and inconvenient for engineering purposes. Therefore metallurgists and chemists are searching for alloys and materials which would be superconductive at higher temperatures. A superconductor made of germanium and niobium has a critical temperature (the point at which the alloy becomes superconducting) at 22.3 K. This temperature can be provid-

ed with liquid hydrogen rather than liquid helium, a process considerably cheaper and easier technologically. The preparation of materials with superconducting properties at room temperatures—not a theoretical impossibility—would produce a real revolution in technology, specifically in transportation.

But for all its worth, the linear induction motor has a number of significant shortcomings. A stationary member extending along the whole track is expensive. Although the track repair and maintenance costs are lower, the energy consumption of this configuration is higher than that of the tubular counterpart. The efficiency of this type of motors is lower than that of ordinary d.c. motor, which equals 0.92. The efficiency of a LIM with an aluminium reaction rail is 0.88, while that with a steel rail is 0.7.

The most sensitive shortcoming of these engines, however, concerns the small clearance between the moving and stationary parts, which reduces the safety of the train at high speeds. Current supply to the moving train is also difficult. These shortcomings force us to turn our attention to the synchronous motor.

In the linear synchronous motor, the stator winding is connected to an a.c. supply, while the rotor winding is fed by a direct current. The interaction of the magnetic fields of stator and rotor produces a torque which rotates the rotor synchronously with the stator field.

To start a synchronous electric motor several methods are used: (i) an additional low-power pony motor (usually an induction motor) can be used to accelerate the synchronous motor in

the absence of a load or (ii) the supply frequency for the stator can be gradually increased or (iii) a rotating electromagnetic torque can be induced by the interaction of the stator magnetic field and the field of the current induced in either the field winding or the rotor core. The latter technique, which essentially is to make the motor behave like an induction motor when starting, is the most popular of the three.

In a linear synchronous motor, the stationary member, the stator, consists of a system of rectangular loops placed along the whole track and connected to a three-phase supply. The movable member of the motor, the rotor, is a series of identical rectangular loops each energized with direct current of the same strength but so that the polarity of each loop is alternated. Since the stator current in each loop is shifted in time and space one third of a period the overall result is a magnetic field travelling along the track. When this field interacts with the rotor currents it produces a propulsive force that causes the rotor to move along the track.

A linear synchronous motor becomes quite efficient when the rotor winding is made using superconducting magnets which can produce enormous magnetic flux densities at low levels of electric power expenditure. In this case an airgap of decimetres between the rotor and stator is sufficient for safe travel at high speeds. It will be noted that a large airgap between the movable and fixed members of the motor enables only a small portion of the stator magnetic field to lock with the rotor windings. That is why large currents are needed to create a sufficient

traction force. However, large currents produce large Joule heat losses, and so without superconductors this motor is infeasible. Therefore, any project for a train using this type of motor assumes that the rotor winding will be made of superconducting materials.

Physically the synchronous linear motors are more complicated than induction ones. The use of synchronous motors is aggravated by the need to protect passengers from the effect of strong magnetic fields.

At relatively low speeds, up to 200-250 km h^{-1}, a linear induction motor seems preferable because of its simpler design, the ease with which it can be started and stopped, and the ability to vary its speed continuously. At high speeds though, synchronous motors are better. Anyway, these motors are the prime propulsion units of trains with magnetic levitation.

Magnetic levitation involves the same basic concepts as linear traction motors. A very simple technique is to use the repulsion of like or the attraction of opposite poles of magnets. Even in the 1950s, permanent magnets were too weak for the magnetic levitation of trains. The situation has now changed since improved magnetic materials like the barium ferrites have been introduced. Therefore several countries have started Maglev programmes for trains using permanent magnets for magnetic levitation. In some systems, magnetic levitation is achieved by the attraction of permanent magnets aboard the car to a steel rail; in other projects the object is to generate levitation using magnetic repulsion.

In Great Britain, for example, one project in-

volves magnetic levitation employing ceramic magnets which contain 90% iron oxide, and some other oxides. The lift of these magnets is 50 times as much as that of steel magnets. The repulsion force of ceramic magnets placed in the track and of those in the car base is enough to lift a five-tonne car 25 mm above the track.

Electromagnets may be utilized for this purpose as well. In 1910, E. Bashelet, a Belgian electrician, built the first model vehicle with magnetic levitation and used an electromagnet to do so. This 50-kg model not only floated in air but moved at $500\,\mathrm{km\,h^{-1}}$, a fantastic achievement for those days. A quarter of a century later, a German engineer Kemper built another model with magnetic levitation and being a practical type of man, he filed a patent. This model also had a magnetic levitation system built around electromagnets. Electromagnets, however, require a stabilization system to control the current so as to maintain a constant clearance between the magnet and the track.

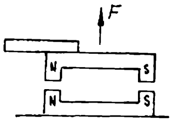
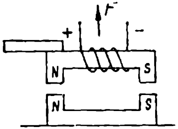
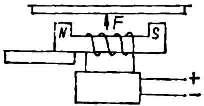
The most efficient method of creating magnetic levitation involves the electrodynamic suspension principle. These suspensions use the concepts of induction and synchronous electric machines we have just considered. An electrodynamic magnetic suspension using the induction motor principle relies for its operation on the interaction of a magnetic field produced by an alternating current flowing through stator windings, with the electric current induced in the rotor windings. As in a linear induction motor, the efficiency of this method improves if the current circulates in superconducting coils.

In the 1930s, a laboratory of one of the physical institutes in Moscow demonstrated the use of superconductivity for magnetic levitation. A small square magnet was dropped into a glass vessel with a lead plate at the bottom. The magnet fell onto the plate, but did not remain there, it jumped up and was suspended above the plate. The vessel contained liquid helium at 4 K under the plate. At this temperature lead is a superconductor. As it fell the magnet induced an electric current in the plate. In the superconducting lead, the current having occurred kept on flowing. A magnetic field appeared with the current; it opposed the field of the magnet and prevented it from falling.

In an electrodynamic magnetic suspension built on the lines of the synchronous electric machine, the magnetic field of the alternating current flowing through the stator placed along the track interacts with the direct current in the rotor placed aboard the vehicle. To improve the efficiency of the electromagnetic levitation, superconductivity is employed to maintain the current flowing in the rotor. If the superconducting windings were placed in the track, the train would be lighter and it would be simpler to protect passengers from the strong magnetic field. This arrangement, however, will have to wait because it is at present prohibitively expensive and technologically infeasible to use liquid helium to secure superconductivity all the way along the track.

Thus, using the various ways of creating magnetic forces, we can obtain a variety of schemes for magnetic levitation as illustrated in Table 1.

Table 1

Levitation scheme	Operating principle	Magnetic cushion, mm
	Repulsion of permanent magnets	2-15
	Repulsion of a permanent magnet and an electromagnet	2-15
	Attraction of a d.c. electromagnet to a ferromagnetic strip	20-40

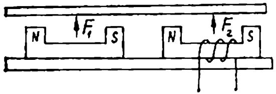
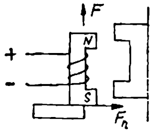
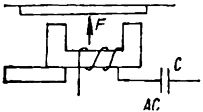
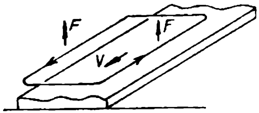
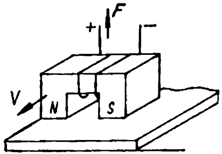
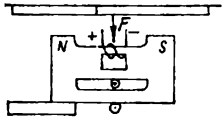
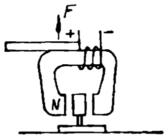
	Attraction of permanent magnets and control electromagnets to a ferromagnetic strip	2-20
	Displacement of electromagnet poles and a ferromagnetic strip	2-40
	Attraction of a.c. electromagnets to a ferromagnetic strip	2-40
	Use of superconducting loops	100-300

Table 1 (Continued)

Levitation scheme	Operating principle	Magnetic cushion, mm
	Motion of electromagnets over a non-magnetic conducting strip	100-300
	Controlled electromagnets with super-conducting coils	20-80
	Interaction of a live conductor with a magnetic field	20-40

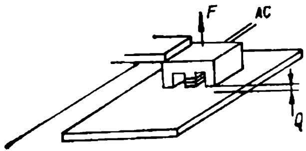
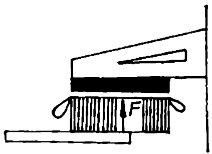
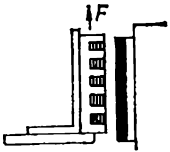
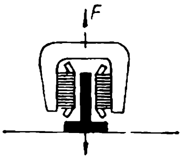
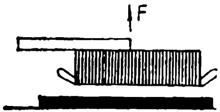
	A.C. inductive suspension	10-20
	Attraction of the inductor of a linear induction motor to a ferromagnetic reaction strip	15-20
	Use of forces produced by special lifting linear induction motors	100-400

Table 1 (Continued)

Levitation scheme	Operating principle	Magnetic cushion, mm
	Expulsion of the inductors of linear induction motors with an asymmetric netic strip	50-100
	Repulsion of a bimetallic reaction strip from an LIM inductor	5-15

To stabilize a train from moving sideways, the concrete bed of the track has vertical loops embedded in it. If the vehicle moves sideways under the action of lateral forces, magnetic forces which counteract this movement are immediately generated to restore the initial "neutral" position. This method of stabilizing the train's forward motion is fairly reliable. In an American project which involves this stabilization system, the force required to move the vehicle a few centimetres away from the axis is comparable to the train's weight.

Physically, the magnetic levitation and magnetic stabilization systems are similar to the arrangement of linear motors unrolled along the track for propulsion purposes.

Humans in a Magnetic Field

An important consideration of maglevtrains which the designer should bear in mind is the effect of a magnetic field on man. Interest in the effects of magnetic fields on biological processes has a long history. As far back as 1600 W Gilbert published a book *About the Magnet, Magnetic Bodies and the Large Earth Magnet* in London. One chapter was devoted to the therapeutic action of magnets. In 1754, abbé Lenoble in France produced and applied magnets to treat nervous diseases and in 1763 treated tooth pain this way. On 29 August 1780, two French physicians Mrs Andry and Turet reported Lenoble's findings to the Royal Medical Society. This year is believed to be the one when the scientific approach to magnetobiology was born.

Further research in the field was however set back by the events connected with the name of F. Mesmer, an Austrian physician. In the summer of 1774, the wife of a certain noble foreigner suddenly felt stomach pains. She asked the known astronomer M. Hell to make a magnet for her to apply it to her stomach. The astronomer told his friend Mesmer about the case. Mesmer requested another magnet for him and began experimenting with the magnet placing it near the painful areas of his patients and unexpectedly discovered that a number of previously incurable cases came to improve. In 1775, the Bavarian Academy of Sciences honoured his achievements in magnetotherapy by electing him a member.

In the same year Mesmer found that it was not the magnet that had produced the wonderful effect on people but his own hands. Since 1776, the word "magnetize" acquired another meaning than simply to influence with a magnet. And although Mesmer himself called the influence of one living organism on another—"animal magnetism" to avoid confusing it with "mineral magnetism" effects on man, the words "mesmerism" and "magnetism" are treated as synonyms.

Animal magnetism was discredited by French official science in 1784, but it survived and later reappeared as hypnosis. The distaste for animal magnetism nevertheless also tainted mineral magnetism, though Mesmer had very little to do with it.

Interest in magnetobiology has recently grown quickly. This is because powerful magnetic fields have been introduced in a number of industries,

and a stream of complaints from maintenance personnel has started concerning malfunctions of the cardiovascular and nervous systems. In addition, the exploration of space and phasing in magnetically levitated trains require the knowledge of how both strong and weak magnetic fields affect living organisms. In space, for example, weak magnetic fields are commonplace, and strong magnetic fields may be employed to protect spacecraft from ionizing radiation.

The interest in the biological effect of magnetic fields has also been stimulated by the influence these fields have been found to have on malignant cells.

A biological system can be modelled as a heterogeneous electrolytic medium where complicated biochemical processes take place in solution. In this system, bioelectric potentials are generated, bioelectric impulses propagate, and liquids with a variety of physical behaviours continuously circulate. Therefore, from the physical standpoint, magnetic fields certainly should have an effect on living organisms.

In 1965, studies were carried out of the effect of a variable magnetic field on the circulation of the conducting liquids in a living organism. Measurements were performed on a laminar flow of an electrically conducting liquid flowing between two planes. The researchers concluded that magnetic fields of $1.6\text{-}16 \times 10^5$ A/m can greatly influence the blood stream through the aorta. All the other conditions being the same, this effect diminishes for vessels of lower diameter.

Further investigations have indicated that vari-

able magnetic fields have different effects on living systems. The circulation of the blood and other liquids is slowed down, the fibres that transmit bioelectric impulses begin vibrating, thus causing distortion and delay of the impulses, orientation and concentration is upset of the biologically active macromolecules in solutions affecting their biochemical reaction kinetics and physico-chemical process behaviour.

Many biological experiments have been addressed the effect of magnetic fields on animals. These have established that they have more effect on males than on females. For instance, the Hungarian physicist J. Barnoty placed young mice into a magnetic field of 480 000 A/m. In two weeks all the male mice had died and the female mice were found to be 4 g lighter than the control animals from the same brood.

It has also been found that a magnetic field affects embryos more than it affects adults. Therefore, researchers recommend that pregnant women should avoid areas of intense magnetic field since it may both physically and mentally handicap the child.

Like radiation, magnetic fields can penetrate the skin and affect any function within the body. White mice placed for a long time in magnetic fields of 32 000 and 160 000 A/m lived by 15 to 20% less than the control group. Human memory weakens in a magnetic field. Even a short exposure to a comparatively weak (up to 8000 A/m) magnetic field (note that at the Moscow latitude the geomagnetic field is about 40 A/m) may affect the productivity of a machine operator.

Powerful magnetic fields can very deleterious-

ly affect living organisms. However, living organisms also cannot develop normally without magnetic fields. American scientists experimented with mice permanently exposed to lunar magnetic field of 100 gammas (1 gamma $= 10^{-4}$ Oersted $= 7.96 \times 10^{-3}$ A/m). The first generation of mice born in this field grew and developed faster than their parents had done. However the next generations were badly affected. The infant mortality increased, while adults were abnormally bald: the skin was swollen and pushed out the hair bags. Dysfunctions of the liver, kidneys, and sexual glands were noted, and tumours were found in various organs.

Other researchers have found that weak magnetic fields may accelerate the healing of wounds, while strong fields can slow the growth of tumours. However, it is far from easy to separate experimental fact from illusion, or not to mistake wish for reality, or even just to avoid sensation or publicity, not to say of the difficulties of excluding psychological factors.

As far as the strong magnetic fields that can occur in magnetic levitation are concerned, especially in vehicles using cryogenic technology, the biomedical studies so far performed suggest that the fields do have a certain danger for human beings. Therefore, measures must be taken to protect the passengers from the exposure to these fields.

Northwards to Work, Southwards Home

Impractical today will be feasible tomorrow.

K. E. TSIOLKOVSKY

The Surprises of Permafrost

The technological potential of the USSR enabled the programmes to develop its North and East. whose vast territories hide considerable mineral resources. The Soviet North also abounds in forest and water resources. The realization of this wealth faces enormous difficulties which are aggravated by the fact that most of the area is in the permafrost zone. Permafrost is the legacy of the severe climates of previous epochs. In one of the regions of the Northwest Yakutia the ice cover is 1450 m deep. The age of the permafrost layers is estimated to be around 40-50 thousand years.

The development of resources in these regions involves exploration and survey, wells drilling, and pipe laying. We should not overlook, however, that the permafrost becomes unstable when man meddles; he disturbs the plant cover and soil, the microrelief and snow cover, to name a few. Thawing soil rapidly becomes a viscous mass unable to bear construction loads. A great nuisance is frost upheaval of soil—a gradual bulging of a road bed or a foundation of a structure when large ice lenses are squeezed to the surface.

For a better insight into this phenomenon consider the behaviour of a liquid at a liquid-solid interface. In solid water, or ice, the constituent particles (molecules) move in ordered portions, whereas in steam they move at random. In liquids, there is some order but only for small distances between the molecules, and this order is due to interatomic or intermolecular interactions. In water the hydrogen atoms of one molecule are attracted to the oxygen atom of another. As the intermolecular distances grow the forces abate and the order rapidly disappears. At a liquid-solid interface, the solid surface affects the structure of the adjacent layer of water, which is 10^{-8}-10^{-9} m thick, and alters the physico-chemical properties of the layer. The soil in permafrost regions is a porous structure impregnated with water. Coming in contact with the solid particles of soil, the liquid has different properties from those liquid in the bulk has.

The behaviour of water in the capillaries of porous soils at low temperatures has been reported for a number of experiments. In one experiment, water was frozen in a capillary, a gas pressure was applied to one end of the ice column, and then the temperature was allowed to grow. At a temperature somewhat below 0°C the ice column began slowly to move along the capillary.

Experimental evidence suggests that frost upheaval of soil at low temperatures (also called thermocrystallization transfer) is due to air bubbles trapped in the ice or soil pores. In an experiment, an air bubble was trapped in a capillary

ice. A temperature gradient was set up such that the ice melted and evaporated from one end of the capillary and water was frozen at the other end. As a result, the air bubble slowly moved to the warm end.

In frozen soils this process is substantially accelerated by the transfer of the viscous unfreezing boundary layer of water that occurs in thin pores. This mechanism shows that frost upheaval in soil is the accumulation of ice in the pores of the soil or foundation beds. As a result of these studies, a series of scientifically founded recommendations has been developed to cope with permafrost. Construction work in northern regions faces a number of engineering problems. For example, the seemingly simple task of earthing the posts of an electric transmission line becomes almost intractable because permafrost is an insulator and there is no sense in electrically connecting a pole to this "ground".

Greater challenges are faced by road engineers in permafrost areas. In addition to the large material expenditures and labor input, the difficulties of road engineering in these conditions are aggravated by the rapid deterioration of existing roads. Therefore the development of northern regions needs a transportation system for which traditional roads are unnecessary. This includes both transport communications on trunk routes between industrial centres and new development areas, and vehicles for pioneering trips into unpopulated areas to transfer heavy goods and equipment over difficult-to-reach terrains. The latter can be achieved using air cushion vehicles. At present, a number of ACVs are under

development, and some are already in use in development areas inaccessible for conventional vehicles.

ACVs for Northern Regions

Self-propelled overland ACVs use as an alternative support both cushion and wheels or caterpillar tracks. The functions of support and propulsion are separated in such vehicles for ground pressure control, with most of the load taken up by the air cushion confined in the bottom by a flexible skirt. This enables the air pressure on the ground to be as small as 0.2×10^{-3} MN m^{-2}, which is about one hundredth the pressure produced by a wheeled vehicle and one tenth of that produced by a track-laying vehicle. An insignificant unbalanced portion of the vehicle's weight is used to give the traction wheels or caterpillar tracks adhesion in propulsion. This "gentle" pressure is enough to move the vehicle and is fairly sparing on the underlying soil which is not deformed or cut up by the treads. The ground grip can be altered by varying the pressure in the air cushion so as to cope with differing soil and travel conditions.

During tests on sea-shores with sand that had a density of 1.9 g cm^{-3} and water content of 29% an experimental model of overland ACV moved at 15-20 km h^{-1}, whereas a landrover type vehicle slipped and stopped.

In 1969, a self-propelled caterpillar vehicle assisted by an air cushion was built which could carry 9 tonnes of payload over an impassable swamp at 50 km h^{-1}. The machine had an extra

power and could have hauled air-supported cargo platforms (hoverpallets). In 1972 this ACV-hoverpallet rig was demonstrated at the First All-Union ACV Conference in Tyumen.

Cargo hoverpallets with constant air-cushion pressures are designed to support loads over poor load bearing (low-reaction) surfaces. These platforms can be towed by rubber-tyred or track-lying tractors, snow or swamp tractors, or by air-cushion towcraft (Fig. 10). A single tractor can tow several platforms since their resistance to motion is rather low. To increase their riding control and stability, hoverpallets are often designed with wheels in contact with the ground.

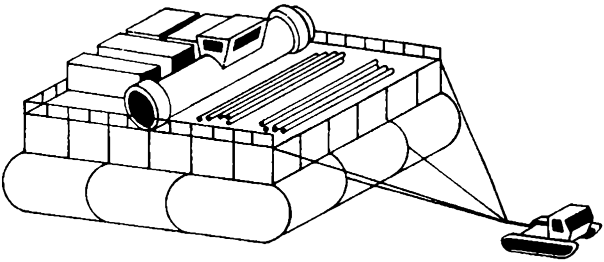


Fig. 10

Hoverpallets can handle payloads of many hundred tonnes. One Canadian company, for example, planned to develop an air-cushion platform with a load capacity up to 3840 t to transport over rough terrain cumbersome mechanical equipment such as drilling towers, certain assemblies and mechanisms of drilling rigs, pipes, bulky heavy loads, diverse structural members, and wooden materials.

Another Canadian company has developed air-cushion platforms of 1, 15 and 25 t capacity capable of transporting loads without harming tundra moss cover. Loaded to full capacity these platforms develop ground pressures of $3.5\times\times10^{-3}$ MN m^2. Water-tight compartments of these platforms ensure their buoyancy when moving over water.

A one-tonne hoverpallet, for example, is made with a steel frame. The centrifugal fan generating the air cushion is powered by a combustion engine of 81 kW (110 HP). The air cushion is made multisectioned and is established via a two-circuit arrangement of high and low pressure contours. This arrangement enables the vehicle to operate with a high pressure, so it can develop a higher lift for a smaller cushion. In addition, the air from the high pressure chambers (eight in number) flows into the low pressure cavity. This arrangement lowers the amount of air that escapes and reduces the rate of air outflow through the clearance of the skirt to mitigate harm on the vegetation cover still more. The operation of several independent air cushions, in place of one, improves the platform's performance over rough terrains and it can negotiate obstacles up to 0.45 m high. The platform is made in modules, so it can be broken down and transported by aircraft.

In 1971, also in Canada, a 112-tonne hoverpallet was constructed. It has a box-type frame with inflated trunk segments (jupes) fixed around its perimeter to trap the air. The platform base can lift 1.2 m above the ground and can climb slopes up to 40°. The air cushion is generated by

two centrifugal fans powered by two diesel engines of 471 kW (640 HP) each. Each fan supplies air at up to 40 $m^3 s^{-1}$ at a pressure of 7×10^{-3} MN m^{-2}.

This hoverpallet may be used for both personnel and cargo, and can carry dwellings for 35-40 people, the ancillary buildings for the crew, and the like. The cruising speed of this platform is 10 km h^{-1}. When in motion, the air in the cushion never warms up enough to melt the tundra cover. However it can be made hot for a short period to get the platform unfrozen from the ground when starting by diverting the exhaust gases to the cushion. Transporting freight by hoverpallets is about 8 to 10 times cheaper than using conventional high-capacity trailers.

Hoverpallet transporters can be configured with either fixed or removable air cushions. On wheeled transporters, the air cushion may be generated to distribute the concentrated axle load more uniformly over the large bearing surface. This appreciably facilitates the transportation of heavy goods. Estimates indicate, for example, that a transporter without an air cushion when crossing a bridge with 7.5-m long spans may only carry 125 tonnes of payload, whereas it may carry twice that load when supported by an air cushion.

A removable flexible skirt may also be used for air handling unwieldy or heavy goods. In the Tyumen region of the USSR in 1964 a transportation system was used to convey 170 tonnes of a drilling tower with a rig and a pump a distance of 12 km. A flexible skirt was installed around the tower's base. An air cushion was

generated by centrifugal fans powered by the diesel engines of the tower. The pressure in the cushion was 3×10^{-3} MN m^{-2}. Two swamp tractors hauled the tower, which cleared troughs, ditches, small lakes, pipelines, and earth banks up to one metre high. This operation saved the tower from being dismounted and then reassembled at a new place. This application of the air cushion improves the productivity of drilling work by several times.

Air cushion vehicles and hoverpallets will be widely used in remote areas that are being developed primarily for extracting and conveying mineral resources. They will considerably cut the expenditures needed for facilities of secondary importance, primarily for roads. Today, the first construction project in the area of a new oil or gas field or other deposit involves road. Temporary dwellings for the workers and warehouses are built from suitable miscellaneous materials. After the pioneer crews of workmen their families come, along with the related services. The area soon becomes overgrown with temporary structures and a network of roads.

Even a single track made by a cross-country vehicle across tundra remains without moss cover for decades and may erode into a deep rut. The roads used for hauling log harm the neighbouring forest in Siberia. If the natural structure restraining sand dunes or saline soils from spreading is degraded the sands and soils begin to migrate.

The foot prints of air cushion vehicles involve pressures of only 0.3×10^{-3} to 7×10^{-3} MN m^{-2}. This pressure barely harms the vegetation and practically eliminates resistance to motion. In

fact, this resistance comes only from the drag due to the flexible skirt as it brushes the ground or the rolling of unloaded wheels. Therefore, ACVs will mitigate considerably its impact on the environment as this is taking place in the development of new remote areas.

Airships may also contribute to environmental protection where new deposits are commercialized. They can transport ready-made houses and technological modules to be assembled on site so that temporary dwellings and storehouses need no longer be built from scarce local materials.

Thus, the development of new areas in permafrost regions, in the siberian taiga, or in deserts should put ecological criteria first. For these regions vehicles should be developed that would not disturb an almost irredeemable ecological balance.

The Development Strategy for the Soviet North

The development of a new deposit involves the construction of a town, the phasing in of the growth of services and associated production. This first stage in the development of a new region is followed by an operational and expansion period. The entire production programme will require a continuous flow of construction materials and equipment, let alone the materials needed for the people that will live and work there. All these activities require reliable transportation systems.

It should be recognized that transportation re-

mains the most challenging engineering problem in the development of the North. The vehicle fleet of the Soviet North includes hundreds of thousands of trucks. In winter, when frozen and therefore more reliable routes can be ridden there most efficiently, the failures of parts and units of automobiles mainly due to brittle fracture at low temperatures increase by a factor of 5-6 and even 10 times compared with the failure rate in summer. This means that a large proportion of the trucks stand idle and a great deal of money is needed to bring them back into service. These expenditures increase if we account for the losses accrued by the disruption in the work schedule of the construction or industrial enterprises involved.

The climate in permafrost regions is far from favourable for people. Of course, some people can work for long periods in the most unfavourable conditions, such as polar explorers on drift stations or meteorologists on remote stations with severe climates. However, they make up a small group of pioneers but many people are needed to open up new areas, and most of these will be newcomers to the North. Those people who move from other climatic zones are affected the most.

Experts who study living conditions in the North use a "discomfort coefficient" to describe the severity of local conditions. This coefficient indicates the proportion of a time (say of a year) during which it is not recommended to engage in outdoor activities. In the Northern Yakutia, for example, this coefficient is 0.32, i.e., for a third of the year it is better to stay indoors. This value of the coefficient is associated both with

the low temperatures and the strong winds the region suffers.

The climatic effects of local conditions on humans living in the North are manifold and pose many enigmas. In Yakutia, for instance, it is uncertain why most of the illnesses the local population suffer involve less pain. Ulcers are uncommon while a nervous disease called *Viljui encefalomielite* affects many of the adults.

The hardships faced by the builders of the Urengoi-Uzhgorod gas pipeline have been reported by Helmut Weinand, a West German correspondent. "At the construction site I was introduced to Vladimir Vasiljev, the crew leader.

"Windows require at least three panes of glass here, otherwise it is not worth starting constructing", he explains. "Broadly speaking, construction costs here are five times those in metropolian areas. Schools and kindergartens are still more expensive to build. Therefore an entirely new technology is required."

He noted in passing that assembling structures at temperatures of minus forty degrees Celcius was very hard and the metal could deform and there was a risk that structural members would fracture.

Anatoly Pisarenko, the trade union leader at the Nadymgasprom Agglomerate, carried on:

"Nature has taken great pains to hide its wealth. Our gas is hidden under permafrost and swamp. Nine months of the year is winter here. Sun appears at 11 A. M. and by 2 P M. it is already dusk. As compensation for the dark winter, the short summer brings us white nights. To make it dark at home we have to draw all the

curtains. However, it is the legions of mosquitos that make the summer very difficult. On a still day you may leave a sheet of paper on the air, and it will only slowly float to the ground. Clouds of the pests virtually keep it afloat."

All this makes us think other strategies for exploiting the wealth of the North. It appears unwise in most cases to move many people to northern regions and build towns for them, even if these would be built under cover and provided with an artificial climate. It would be more efficient from the standpoint of both people health and economics to have a rota schedule for operating the production facilities. The number of people on each shift would be large but the shift would not be too long so as not to tear people away from their families and homes. Nevertheless, a shift arrangement could be introduced in developing regions if transportation was available that could transfer the requisite personnel in two or three hours from one climatic zone to another.

The availability and quality of vehicles operating within the familiar climatic zones divide them tentatively into subzones. This division is of significance because the availability of transportation considerably influences the optimal choice of the settlement area.

In the USSR, the cold climate zone to be developed (regions to the north and east from the perennial January isotherm of −20°C) includes the European North, the north of West and East Siberia, and the arctic deserts of the northeast. It can be divided into the following subzones.

Subzone 1, arctic. The transportation network consists almost exclusively of waterways—rivers

and sea, for example the Northern sea route from the west to east across the Arctic Ocean. The rivers are only navigable for a short summer period. Cargo is piled up on the shore to be taken further inland by trucks or tractor-sledge rigs over winter roads for 3-4 winter months. During the summer these roads are impassable and no ordinary vehicles can operate on them.

Subzone 2, subarctic. During the summer, most of the plains are virtually impassable for ordinary vehicles. Where the vegetation cover has been disturbed and can no longer protect the permafrost from summer temperatures, the area becomes a swamp. Railways and roads are almost nonexistent. Goods are taken to the ports by water or by air to be transported to their destination over the winter routes.

Subzone 3, the northern area of the cold climate zone. Most of the terrain is impassable in summer. No roads exist for automobiles and there are only short lengths of railway. Goods are mainly conveyed by airplane and in winter by track-laying vehicles.

Subzone 4, the eastern portion of the cold climate zone. This area has railways and highways that can operate all-the-year round. Waterways are also used.

To summarize, the vast areas of the cold climate zone are impassable for ordinary ground vehicles. Constructing railways and highways requires enormous capital investment. The absence of a transportation network sets back the development of these regions, as so far goods have to be transferred northwards on a seasonal basis.

Let us look at the distances that separate these

subzones. For example, at the longitude of Omsk, the distance between subzones 1 and 3 is 1200 km. To cover this distance in two or three hours a speed of 500 km h^{-1} is required. These speeds are available with winged tracked air cushion vehicles, and these vehicles can alter the development strategy for new territories. They can bring large numbers of people to their jobs in northern regions within two or three hours from cities some 1000 km to the south. The people will spend a few days or a week at their jobs and then return home to their families.

It would be natural to ask whether these TACV trains can operate in the northern conditions and, above all, whether it will be possible to lay a track for these trains through permafrost areas.

The track is laid on trestle supports with piled foundations. Today there are several ingenious techniques for piling in permafrost. For many years piled foundations have been exploited to support nine-storey apartment houses and industrial structures. Because the train carriage is coupled to the track surface through an air cushion possible deviations of the monorail from the vertical on the order of millimetres should not be a cause for accidents.

The train wings unload the track. This simplifies the construction considerably, reduces its cost, and trestle supports may be erected quite far apart, which helps preserve the permafrost soil cover. All the components of the track can be manufactured in work-shop conditions and assembled on site. Consequently, erecting a track should minimally disturb the soil cover in the construction area.

Winged air cushion trains are preferable to magnetically levitated trains for the development of new regions. They are capable of high speeds at relatively low power requirements since in contrast to magnetically levitated trains their specific power requirements decrease as the speed increases. This is because of the growing aerodynamic lift generated by the wings at higher speeds and the use of the aerodynamic pressure of the oncoming air in the air cushion, which cuts down the lift fan power. In addition, an air-cushion track is much cheaper than a magnetic one, and it is simpler to maintain in the severe conditions of the North. As for the major advantage of the magnetically levitated trains, their silent operation and the absence of exhaust gases, they are of no significance in the expanses of northern regions.

The designs developed for the chassis-track system, traction engines, fans, train hull, and wings guarantee the safe operation of the trains in the most severe weather conditions. It will be noted that icing is not of so much danger for TACVs as it is for ordinary vehicles because it involves no direct contact with the track surface.

Thus, the high speeds of wheelless trains open up new solutions for the very complicated problems associated with the development of northern regions, specifically, they enable the exploration of areas large distances from urban areas. But how about economy? After all, an aircraft can also travel at similar speeds and can fly 1500 and even 2000 kilometres within two or three hours. It will be understood, however, that to transport tens of thousands of people regularly

to their jobs and back home by aircraft would be economically prohibitive.

This is where the advantages of a new type of transportation—winged trains on a thin air cushion (virtually an air lubrication layer) propelled over a trestle can be seen at their best. Owing to the screen effect, the lift power requirements of the trains are only a fraction of those of jet aircraft. In addition, the payload to gross weight ratio of the train is far better than that for airplanes. TACVs do not need to carry fuel for the whole trip since they can be refuelled at intermediate stations. They also do not need the bulky and heavy undercarriages aircraft do to take up the weight and dynamic loads of landing and takeoff, nor do they need expensive navigation equipment nor the devices for takeoff and landing.

An air-cushion—monorail system appreciably decreases the dependence of TACVs on weather conditions, while its capability to control the train's lift to weight ratio provides for the stable motion at various wind loads and under changing atmospheric conditions. Even in the North, the operation of trains whose track is elevated on a trestle will be practically weatherproof. TACVs are far safer in operation than aircraft, as they travel along a track and do not have the dangerous phases of takeoff and landing.

The suitability of the track for electric cables, wire communications and other lines, may considerably facilitate the automation of TACVs operating schedule and the whole railway line operation, and convert the track into a supply line for newly developed areas. Winged trains can

transport both people and the small-size cargo necessary for the continuous operation of the production activities in the North.

This application of winged TACVs to the development of northern areas was suggested by the author in 1972. A design establishment was asked to assess the project economically. The experts, however, invoked cost effectiveness techniques normally used to estimate the economic feasibility of new underground systems. These systems are known only to be economically viable when they service at least a million people. Since the experts failed to find a million people concentrated anywhere in the northern regions, they considered the project uneconomic.

This estimation of economic viability cannot be fair for the case of winged TACVs in the northern areas. Economic feasibility here should not be estimated using amortization on the basis of ticket receipts but rather should be assessed by the effect which could be gained when there is no longer any need to construct houses for workers in the permafrost or severe climatic areas, when natural resources are developed at the increased pace, with an exceedingly low environmental impact due to TACVs. TACVs will provide for an integrated approach to the development of high latitude regions. The point of departure in an economic feasibility evaluation of high-speed wheelless trains should in this case be the fact that the country will have to develop new territories in severe climatic zones.

The separation of production and living areas is consistent with the general trend in the development of human civilizations. In future, the

heaviest and most dangerous types of production, which have deleterious ecological impacts, will be taken beyond the Earth, and in the more distant future the Earth will be the home of a mankind who works in, explores, and develops space.

Trains for Vacation Flights

Much is to be done on Earth,
do it faster.

KLARA ZETKIN

Wheelless Trains on Short Sections

What a precious possession is a man's life, and how he spends the time of this life is far not a trifling thing. The best use of our time is an important social problem, and the transportation media are to cut to a minimum the time spent en route. The possible exception is perhaps the sightseeing trip. For example, tourists spending their vacation on cruises might like to travel on a steam peddle or a riverboat.

In a time of technological revolution, urban communities and especially suburbs are snowballing. In the United States, between 1951 and 1960, the population grew 4-5 times faster in suburbs and satellite towns than it did in the metropolitan areas. From 1961 to 1970, the urban population grew 1.7% while the suburban population grew 25.7%. According to some estimates, the urban and suburban population in the USA by the end of the century will account for 70% of the entire population. Today the growth rate of urban and suburban areas are 10 times the population growth of the planet. Therefore, cutting down commuting times is of primary importance.

The admissible length of a commuter trip, i.e. such that is not detrimental to working activity of the passengers, should not exceed 40 minutes. A special study on this subject revealed that the transportation weariness of commuter passengers incurred at the existent speeds and curve radii degrades the labour productivity of production workers by 5 to 10%.

The situation in Japan illustrates how acute the problem of fast transportation of large groups of people is in densely populated areas with a high concentration of production enterprises. The Tokaido megapolis is now populated by about 50 million people and contains about 60% of the country's industry. From 1964 to 1971, the New-Tokaido railway line handled 400 million people. Now even this line, which uses some of the fastest expresses in the world, is unable to handle the passenger traffic. It is assumed that by 1990 the population of this area will have grown to 80 million people. Consequently, the problem of mass transit in densely populated areas cannot be solved using traditional types of transportation.

In *New Modes of Transportation and Movement* (Transport Publishers, Moscow 1975) the authors write: "Our current land passenger transportation faces high requirements which have a tendency to increase with the pace of technological and social progress. These requirements include (i) regular and failsafe transit facilities under all weather conditions; (ii) high speeds and safe operation at these speeds; (iii) maximum comfort including noise and gitter-free operation and other voyage conveniences; (iv) high throughput;

(v) minimal deleterious effect on the environment, including atmosphere and noise pollution, narrow route paths, grade separation crossings with other transportation routes and communication lines; (vi) maximum industrialization of vehicle construction. To date these requirements have been best met by railways, underground systems, and trams".

But, as we have already seen, even the fastest and most advanced railway expresses on the Tokaido line cannot provide the necessary passenger throughput which can only be increased by increasing the traffic speed. Because the Japan expresses have already approached the speed limit for wheel-rail systems, the only resolution is to abandon the system and adopt wheelless vehicles with air cushion or magnetic levitation systems.

A sizeable effort is now underway in Japan to develop a magnetically levitated train which will harness superconducting magnets. The Japanese State railway authority has been testing models of these trains since 1972. One model had only the support magnets superconducting, while rollers and sledges were used for stability control and guidance. On an experimental 480-m long track section the 3.5-t model developed a speed of 60 km h^{-1}. On a 7-km long section, the speed was 500 km h^{-1}. The commercial cost of the railway per kilometre with magnetically levitated trains is estimated to be $1.55 million, and the replacement of the existing expresses on the New-Tokaido line by trains with superconducting magnets will run into $800 million.

However, the Tokio-Osaka section is longer than an ordinary commuter line, being an intercity trunk line. The pacing factor for through traffic is the cruise speed, and the large capital investments for the construction of high-speed railways with magnetically levitated trains in totally urbanized areas should pay off. On an intercity route, with no intermediate stops, the train has enough time to accelerate to high speeds.

Quite another thing is when a heavy passenger traffic must be handled over short distances, say, shorter than 100 km, in suburban areas or across the city. The high population density of these areas prevents utilization of very noisy or polluting vehicle systems. To compound the problem, multiple stops are required on such routes. These requirements are best met by trains with magnetic levitation operating at lower speeds than those possible on the Tokaido line. Because the power requirements for magnetic levitation decrease considerably at lower speeds and also a train designed for lower speeds can recur to other means of producing magnetic levitation, the railway lines with magnetically levitated trains may turn out to be considerably cheaper for short sections.

Depending on the type of terrain, the position of the populous areas to the track, and the population density in the suburban zones TACVs can be used. They are noiser than magnetically levitated trains but have a number of advantages including the absence of strong magnetic fields, from which passengers will apparently have to be protected, and lower construction and opera-

tional costs for the track than a magnetically supporting structure. However, the low speeds developed by a train that must stop frequently render wings unloading the air cushion useless, nor can the dynamic head be used for air-film lubrication. In the circumstances, it may be

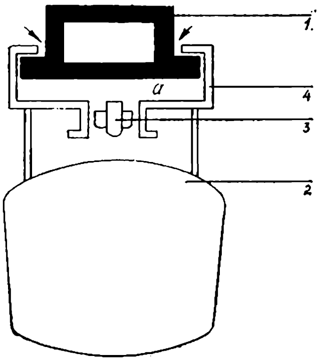


Fig. 11

worth pumping the air cushion in using stationary wayside compressor stations via a system of air ducts in the track. The main feature of this cushion-pump system is that the principal source of noise—the fans in the train—will be eliminated. Stationary wayside air compressing stations can be used at stops, on the sections where noise attenuation is a must, or over the entire line. In the latter case the train need have no onboard fans and so lose considerable mass. The suitabil-

ity of a particular configuration should, however, be decided on the basis of a cost efficiency analysis for a specific route.

The development of urban and commuter TACVs is underway in France, United States and some other countries. The French, for example, have developed a train programme called URBA which includes a family of suction suspended vehicles. These derive their support lift by evacuating the air from a negative pressure chamber between the vehicle's suspension structure and the guiderail. The operating principle of this suction suspended system is illustrated in Fig. 11. The cabin (2) is suspended from an "air bogie" (4) threaded on the guiding beam (1). The fan (3) sucks air from the negative pressure chamber *a* to make it sub-atmospheric. The pressure difference causes the bogie to lift clear of the upper beam floor, where a negative air cushion occurs. The airgap, i.e., the height of the negative air cushion for this arrangement, depends on the fan capacity. This design is favourable for its low noise level for the passengers inside the cabin because the source of noise, the fan, is located outside. To dampen the noise still further, the vehicle is propelled by an a.c. linear motor. The suction suspension structure almost completely eliminates dust and spray.

Two versions of URBA vehicles were designed and tested for an urban and commuter transportation. They were a 30-passenger vehicle for operation in medium-size towns and a 100-passenger vehicle for medium and large cities. The principal data for these vehicles, the URBA 30 and URBA 100, are summarized in Table 2.

Table 2

	URBA 30	URBA 100
Vehicle net weight, t	2.2	7.0
Gross weight of vehicle with passengers, luggage and freight, t	4.5	16
Length, m	8	12
Width, m	2	2.6
Height, m	1.8	3
Maximum speed, km h^{-1}	80	100
Thrust power of LIM, kW	80	120
Power of suction suspension system, kW	40-60	70-100
Air rate in suction system at normal conditions, dm^3 s^{-1}	2400	10 000
Starting acceleration, m s^{-2}	1-1.5	1-1.5
Braking deceleration, m s^{-2}	1-1.5	1-1.5

A 4-km long experimental line for the URBA 30 vehicles was put into operation in Lyons, France, in 1970. Fig. 12 shows a transverse section through the URBA system. The guide rail (1) is a metal beam 1200 mm wide and 1500 mm high, suspended from reinforced concrete supports (3) by cantilever beams (2). One metre of the metal beam weighs 0.5 t for a single track and 0.9 t for a twin-track line. The supports are 30 to 80 m apart. The guide beam contains a suction suspended bogie (4) from which the cabin (5) is suspended. Air turbines within the bogie produce the sub-atmospheric pressure. The stator winding of the LIM is also within the bogie, while the reaction rail (6) is placed on the beam structure.

The passenger transport capacity of this sys-

tem is a function of the number of vehicles comprising the train and estimated as being from 4 to 10 thousand passengers per hour for the URBA 30 and from 10 to 30 thousand passengers per hour for the URBA 100. To compare, the capacities of a tram or Metro system are 4 and 30-50 thousand passengers per hour respectively.

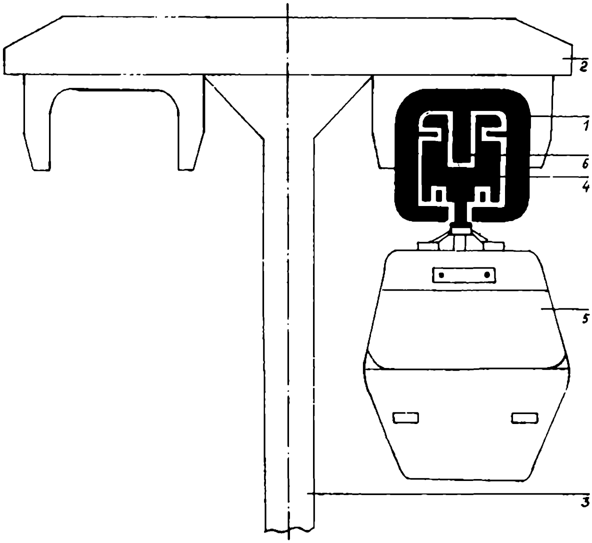


Fig. 12

The production costs for the URBA system were apportioned as follows: vehicle, 10%; electric gear, 16%; track, 54% (supports, 25%; guide rail, 29%); R&D work, 12%; and miscellaneous, 8%. Most of the expenditures were absorbed by the construction of the track. How-

ever, a twin-way URBA track costs only 5-10% of an underground line and about 40% of an open railway line.

A TACV system conceived in the United States was intended to serve 130-160-km long sections passing through a densely populated area, at a cruise speed of 240-320 km h^{-1}. The 200-seat vehicle belonged to the family of craft called Levacars. A thin air cushion was generated in several levapad sledges that surrounded a conventional rail. To do this, two turbocompressors provided a pressure of 0.1-0.7 MN m^{-2}. About 120 kW was needed to propel the craft at 320 km h^{-1}, 960 kW to climb a 20% upgrade at 240 km h^{-1}, 1550 kW to feed the air cushion, and 220 kW for side stability air pads. Consequently, attempts to use existing rails for TACVs without aerodynamic lift provisions bumped into prohibitively large power requirements for suspension due to the high pressures in the air cushion.

Short-journey wheelless trains are economic for passenger transit from city centres to airports or between the airports of a single city. These vehicles have become very urgent in the world's largest cities, such as New York, San Francisco, Los Angeles, Washington, Paris, London, Tokyo, Moscow, and Leningrad.

A serious transportation problem arises when passengers from flights arriving at one airport have to continue their journeys from another. These difficulties are compounded by the considerable distances between the airports, as each of them is normally quite a distance from the city centre. The British, for example, planned to

build or enlarge a London airport and connect it with the city by a TACV (or maglev) system. The airport should handle annually 30-32 million passengers. The overland journey time to this airport should not exceed 20-25 minutes. A British airport transit system requires a train capable of speeds of 400 km h^{-1}. It will have a double suspension system (with a resilient track surface) and shock absorbers, carry 100 passengers, and weigh 23-28 tonnes. The power requirement for the air cushion fans is 1000 kW. The vehicle is designed to be propelled by a double inductor LIM, the total power for the fan and motor amounting to about 4000 kW at 400 km h^{-1}.

The cost per mile of a twin-track line and the vehicle itself runs into £0.7 million. By comparison, the cost of a six-lane motorway is £1 million/mile. The feasibility study indicated that the construction of such a track is economically feasible. The possibilities of links between London and Manchester and the Gatwick and Hearthrow airports are being studied.

In the United States, TACVs are under development to connect Los Angeles and Las Vegas with Polydeil airport 69 km apart. The track would be 416 km long. The maximum vehicle speed would be 500 km h^{-1}. The guiderail would be a U-section beam placed on supports 30 m apart. The vehicle is designed to be propelled by a three-phase LIM, with a reaction rail in the middle of the track. The design power of the motor is 5.89 MW (8000 HP). The train will take 5 km to accelerate from halt to a speed of 480 km h^{-1}. The maximum acceleration possible

is governed by passenger comfort and should not exceed 0.2 g. At 480 km h^{-1} the vehicle will ride so smoothly that it will be more comfortable in its cabin than in a modern jumbo jet. This line will be by length an inter-city route.

Wheelless Trains over Long Distances

Speed and economic performance are the major criteria of wheelless train systems for long-distance lines. Here the speed is no longer limited by frequent stops. Speed and economy are interconnected factors. As the speed grows the time passengers have to spend en route shortens, the capacity of the track increases, or, with a limited passenger traffic, the number of trains serving the line may be cut down. On the other hand, higher speeds mean higher expenditures, but these depend on the vehicle system being used.

At high speeds, considerable power is expended to overcome aerodynamic drag. In general, this power requirement is decided by the profile and dimensions of the vehicle and is independent of whether it has a magnetic or air suspension. Nevertheless, at 400 km h^{-1} or faster, the power requirements and hence the operating costs of magnetically suspended trains are higher than those of TACVs. This is because at high speeds magnetic levitation costs more than an air cushion, the expenditures for the former increasing and for the latter decreasing at higher speeds. When winged TACVs move on an air film over a horizontal section at 400 km h^{-1} or more, the aerodynamic drag is virtually the only resistance

to traction. Therefore TACVs look more economic over long routes.

When selecting the cruise speed or evaluating the economic efficiency of high speed wheelless trains, we should keep in mind how they differ in performance from other types of surface transport which are propelled in contact with a bearing surface. For example, the construction cost of a guide track and its viaduct, and their maintenance are virtually independent of vehicle speed. Higher speeds might seem to call for a more expensive track due to increasing curve

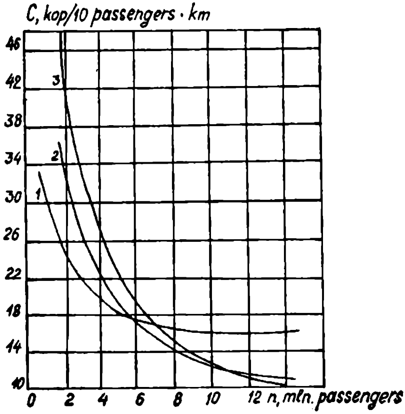


Fig. 13

radii and therefore longer routes. However, the faster speeds assist the vehicle in negotiating steeper upgrades (up to 6-8%) so that the route may be easily laid out over the vertical profile of a terrain instead of keeping to a horizontal

alignment. As a result, higher speeds mean savings in track layout.

Figure 13 shows the reduced costs C for diverse vehicles versus annual passenger traffic, plotted on the assumption that one passenger-hour costs 0.5 ruble (50 kopeks). It will be seen that for an annual traffic of 5-6 million people, the most economical vehicle is the 100-seat coach which is capable of speeds 60 km h^{-1} (curve 1); for 6 to 11 million people, railway trains of 160 km h^{-1} are the most economical (curve 2); and for traffic in excess of 11 million people, 300-seat TACVs capable of 243-285 km h^{-1} are the most economical (curve 3).

Consider which situations call for the high-speed long-distance transportation of annual passenger traffic in excess of 10 million. This need occurs, for instance, during summer vacations when large numbers of people travel towards popular recreation areas. In the USSR, these areas are the Black Sea coastal district, the Baltic coast, the Caucasus, and the Carpathian mountains. Suffice it to say that the city of Sochi on the Black Sea, whose resident population is 100 000, accommodates more than two million people during the summer. The transit of this number of passengers in a short period, and the associated logistics become problems of state calibre. Additional trains and flights are introduced. Buses are used for mass transit; the number of inter-city buses, commuter trains, sea and river ships is increased. Even so the airports, railway and bus stations are overcrowded in summer. Our current transport system cannot handle this seasonal influx of passengers, and experts

predict that this seasonal migration will become larger.

The transportation situation could be eased by flying wheelless trains. They offer high speeds and considerable capacity, so that a large number of people could be transported efficiently and weatherproof. These trains would deliver people directly into the city centre, thus unloading the suburban and city highways and railways. For passenger convenience, where needed, a train would be outstandingly comfortable. Wheelless guided vehicles are propelled without contact with the supporting surface and so are a very safe mode of transportation.

Safety is an essential feature of any monorail track. For example, the Vuppertahl monorail, which has supported wheeled trains for the 60 years of its operation since 1902, has transported over a thousand million passengers and suffered only one accident (when during a snow blizzard the vehicle knocked off a coacher from a hay cart). The 10-km portion of the Vuppertahl track runs above a river, and 3.3 km above a highway. The train carries 105 passengers. Its maximum speed over certain sections is as high as 60 km h^{-1}, its average speed being 25 km h^{-1}. This low cruise speed is due to the frequent stops (totalled 18) and small radii of curvature (as little as 30 m).

Passengers of wheelless trains capable of speeds of 500 km h^{-1} or more will spend less time on a 3000 km trip than those travelling in jumbo jets at 800-900 km h^{-1} since a train will bring them directly to the city centre area and the passengers will no longer need to

wait for their luggage—it will be placed in a cargo bay whence it can be retrieved by passengers as they leave the train. The comfort of a cabin in a wheelless train is higher than that in an aircraft saloon, but a fare will be cheaper. Therefore a possible advertisement might read: "Fly to your vacation by train—this means speed, comfort, and economy!"

Wheelless high-speed trains will not only solve the problem of passenger transit to popular recreation areas but will also bring other areas into prominence. Extending monorail tracks farther south from northern development areas will provide a convenient link to recreation areas for workers in sun-deficient northern regions.

To abate the noise of TACVs operating in densely populated areas they should be propelled by linear motors. Such trains are planned in the United States for the Washington-New York-Boston line which is 710 km long. The cruise speed of the trains will be 320-480 km h^{-1}. The construction cost of a twin-track route made from a U-sectioned guide rail is estimated to be $3.3 thousand million. Development efforts for intercity TACVs are underway in Great Britain, Italy, the FRG, and Japan.

The German designers have concentrated on the development of 1100-km lines with magnetically suspended vehicles carrying ordinary electromagnets. The trains, each carrying 144 passengers, operable for 20 hours a day in both directions, with a 3-minute headway and at 350 km h^{-1} will transport as many as 21 million passengers annually. The construction cost of the system is estimated to be 2.5 thousand mil-

lion German marks. These trains are to connect Hamburg, Bremen, Osnabrück, Stuttgart, and Munich. In future, the line may be extended into a trans-European system.

Magnetically supported trains with ordinary electromagnets consume only small powers for magnetic suspension (about 1 kW per tonne of payload) and their cost is relatively low, but they call for additional power requirements to make up for the eddy currents which disperse the magnetic field. Although small at low speeds, these currents grow with speed to a considerable magnitude at speeds in the order of 500 km h^{-1}. The shortcomings of these trains also include a small (10-20 mm high) gap between the track surface and the vehicle carriage.

Simultaneously in the FRG and Japan two maglev projects are under development using vehicles magnetically levitated by superconducting magnets. The principle advantage of these vehicles is the large (200-300 mm) clearance between the guiderail and the vehicle bottom, which eliminates the strict tolerances to the surface roughness of the track and the requirements for its maintenance. This arrangement improves the operating safety and cuts down the operational costs. The shortcomings of this system include the high cost of vehicles with cryogenic technology, costly track structures, high power requirements for levitation (10-15 kW per tonne of payload) and power losses due to eddy currents, and the need for passenger protection from strong magnetic fields.

The Future Begins Today

> Nothing assists the creation of the future so much as courageous dreams. Utopia today becomes a reality tomorrow.
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Projects, Projects, Projects

In the previous chapters we demonstrated that we can predict the appearance of a new type of transportation. Consequently, we may even now point out how the vehicles should develop in the near and even the remote future, and predict what tomorrow's transport will be like. However, before speaking of future transportation let us review what projects are now at hand and which of the ideas in these projects may prove useful tomorrow.

Because transport is so important for human society, its development attracts much attention in every continent. Papers and magazines all over the world report new and at times rather unforeseen and exotic transportation means and the new principles embodied in these vehicles.

A. Klyachko in his article "Laser levitation" in the Soviet journal *Isobretatel i Ratsionalizator* No 2, 1979, reports a new application for the laser in a water-going "laser transport" The lift for the vehicle body away from the water surface comes from steam generated in a thin surface layer by a powerful laser beam. The first experiments, with a neodymium laser, involved a

light-steam cushion, and then a low temperature plasma cushion was generated. In the latter case, the laser output was focused onto a small spot to increase the temperature in the spot and a laser pulse produced a hot ionized gas rather than steam. As a result, the support pressure was considerably increased. The surge of water away from the illuminated surface also assisted the lift.

The researchers believe that a vehicle supported by a steam cushion may be possible. This principle may also be utilized for soft splashdowns or, conversely, for takeoff from water surfaces.

Hydrofoils, which are now familiar, are limited in speed because increasing the drag causes their submerged foil structures to become unstable. It was found that revolving propellers perform this task more efficiently than static foils, especially at high speeds. A. Bakshinov suggested replacing foils with four rotating propellers more than two decades ago. In April 1961, he applied for a patent for his invention, but though experts acknowledged the invention, they concluded that the power requirements of the vehicle would be close to those of a helicopter, therefore the diameter and mass of the propellers would be very large and that such a machine could not be feasible.

In the event, the resistance of water to rotating propellers is far less than that offered to static hydrofoils. Rotating propellers which provide lift not only support the craft but propel it. In 1971, Bakshinov's machine eventually received due recognition.

New technological developments have included

energy transmission by microwaves and light. A team of American scientists found they could power low-speed airplanes and airships at altitudes of around 21 km with this method. These craft can be used as freight carriers, communication platforms for TV and radio links, forest fire monitoring stations, and intermediate transponder bases for communication satellites.

Dail Reed, an engineer at the Draiden Flight Research Center, has suggested a plane powered by microwaves, that could be launched at three kilometres. To receive this power transmitted from Earth, the plan's bottom surface would carry special rectennas to convert the microwave energy into electric energy to power air propellers. The microwaves could be beamed from the 26-m diameter Goldstone aerial in Northern California. These experiments are aimed at developing a platform for weather monitoring and communications.

In the more distant future, Reed suggests that microwave energy will be used for in-flight fueling airplanes the size of a Boeing 707. This, however, would call for the construction of microwave aerials about 15 km apart along the whole flight route.

Evolution has not left traditional vehicles behind. In 1981, in Japan, a sailed tanker took to the water (Fig. 14). These sails, however, used the latest technological achievements: they are made of sheet steel, and are computer controlled. The computer, for example, finds the force and direction of the wind and sets the sails accordingly: it orients the sail planes, changes their effective area or removes them, keeps the ship

on a heading, provides communication by radio, and is in contact with marine satellites. This system not only saves energy and fuel, attenuates noise, and decreases gas and smoke exhausts, but also improves the safety of navigation and brings the crew down to a few technicians.

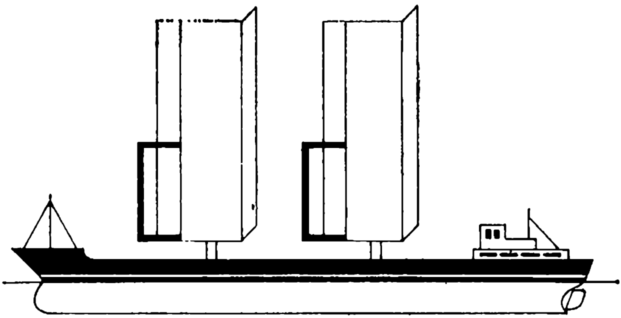


Fig. 14

Modifications of orthodox structures are also evident in airship construction. These are not simply the use of new materials or hybrid structures, such as the combination of aerostatic ships and helicopter rotors or airplane wings, there are also more exotic projects. These include a solar airship propelled by solar energy. Such systems, however, impose certain requirements on weather conditions: clear skies, absence of strong winds; they cannot operate at altitudes higher than 100 m above sea level. There are many areas over the globe where these airships may be used, for example, in Australia, South Africa, and cen-

tral regions of South America. There are many such areas in the Soviet Union.

The surface of a solar dirigible is covered with solar cells that convert solar energy into electric energy to power d.c. motors of thrust propellers. Investigations have indicated that the mass of the silicon-based solar panels would amount to a third the total mass of a flexible dirigible structure. The optimal shape of a dirigible is an extended ellipsoid, and any deviation from this shape in order to increase the surface area and energy output is cancelled out by the poorer aerodynamic behaviour. Today's solar cells, which are 12% efficient, are sufficient to provide a dirigible with six hours of continuous operation at 100 km h^{-1}, and in certain situations ten hours of flight both in summer and in winter. This is because of the very small difference between the highest level of solar radiation in summer and its lowest level in winter for many areas of the globe. The applications of solar dirigible may be widened if it has solar batteries to smooth out the current supply during the day and make it illumination-proof, or if it has fuel elements or another energy supply.

Thus, even modern technology renders the solar airship project perfectly feasible and attractive for many geographical locations.

The list of exotic or already familiar projects for future transport is rather long and can be extended still more. However, most of these vehicles can solve only particular, rather than general, though important problems. For example, they can only be used over a certain geographical zone (solar dirigibles) or transfer heavy and un-

unwieldy loads, such as the 750-tonne air-supported platform constructed in 1974 for the Arabian emirate of Abu-Dabi (Fig. 15). The power plant of the platform is used solely to provide lift. When over water, it is towed by ships, and when over ground is hauled by tractors. The platform was built to deliver equipment for natural gas liquefaction plants from ocean freighters to the shore. On each trip the platform was towed at 5.5 to 13.5 $km\,h^{-1}$ (depending on the wave height) and could take 250 t of payload. The power-to-payload ratio for these trips is only 1.75 $MW\,kg^{-1}$.

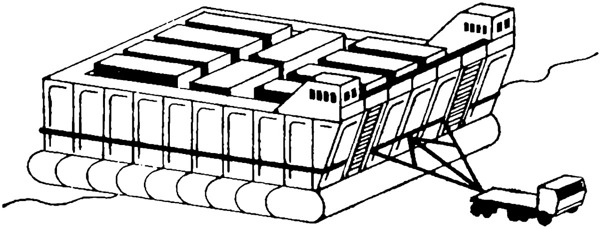


Fig. 15

For mass public or cargo transportation over long distances, the decisive criteria are speed and economic efficiency. What should a designer keep in mind above all when developing a vehicle to meet these criteria? The machine should possess neither wheel nor other mechanical device that limits speed. The only constraint to speed should be air drag. To cope with this, some inventors have suggested that the vehicle should be placed in a tube from which the air

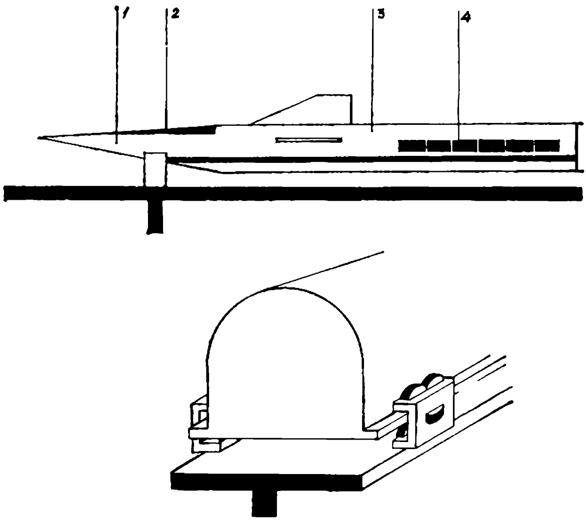
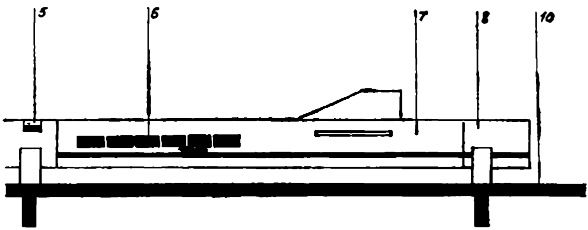


Fig. 16

is evacuated, or that it should travel in the upper atmosphere where the air is rarefied.

In 1955, Professor Kekoya Odzava, Dean of the Science and Technology department at the Meijo University (Nagoya, Japan), was awarded a grant for a supersonic surface transport. Before his team adopted a final version of the vehicle, they had tested about 20 various models made to one sixtieth and one twentieth of the full scale. The final version was a 220-m long and 5-m diameter train consisting of a few modules (Fig. 16): a bow module (1) with the driver's cockpit (2), a cargo module (3), passenger compartments (4) and (6), a machinery module (5),



a car bay (7), and an air braking facility module (8). The train could carry 1000 passengers and 100 tonnes of payload. It was installed in a viaduct and mounted on rollers (pictorial) embraced the train carriage from above, below and on either side. The forward thrust to the train was given by four turbojet engines, each providing 98 kN thrust.

In 1968, a train model moved at 1140 km h^{-1}, and in 1969, in an evacuated sealed tunnel it ran at 2300 km h^{-1}. In 1970, animal trials of the model were carried out, and all the "passengers" felt well. Experts believed that the Odzava transport system was on the verge of commercialization.

Yet the train had no future. First of all, this design could not be deemed feasible on economic grounds. Wheels cannot withstand long operation at supersonic speeds, and in this project rollers are envisaged. These must perform in extremely unfavourable conditions, since they must from standstill move rapidly when suddenly in contact with the train. The system of rollers alignment along the whole track is complicated and costly. It is far from easy to ensure a smooth threading of the train progressing at a

supersonic velocity through E-shaped roller devices spreaded along a track, and negotiating a curve only compounds the problem. The very principle of mechanical interaction of rollers and train at supersonic speeds is not progressive.

G. Kotlov and Yu. Fedorov of the USSR suggest an "underground satellite" project. A tunnel aligned in a subsurface orbit would be evacuated, and an underground "satellite" would then fly at 8 km s^{-1} along it. To match the vehicle's orbit and the Earth's rotation, the tunnel would have to be a circle and in the Equatorial plane, otherwise the tunnel would have to be routed in continuous line passing through the poles, that on the surface would be sinusoidal. The latter routing would cover the Earth's surface better.

To brake one such underground vehicle it is suggested that another be accelerated. The decelerating vehicle would enter a solenoid and the electric current induced as the vehicle brakes would immediately be used to accelerate another vehicle. Having given up all its kinetic energy the first vehicle would stop and be removed from the route to give way to another. The throughput of the system depends in the last event on the overloads admitted in deceleration, as this would decide the braking distance and time.

It has been estimated that the overload should not be above $4g$. Then a vehicle can be decelerated in 7 minutes over 130 km. Only physically fit people can bear these overloads and provided they adopt a certain fixed position in an armchair. Obviously, one cannot walk across a cabin under these conditions. The ultimate value of deceleration in conventional trains in emergency

is 1.5 m s^{-2}. At this deceleration a passenger can move across a saloon and a teacup does not slip from a table. In ordinary operation, the braking deceleration should not exceed 1.2 m s^{-2}, whereas under quadrupled overload deceleration is 40 m s^{-2}.

There are some projects for solving several problems at once. V. Razdumin has come up with the idea of using two cryogenic phenomena—superconductivity and superfluidity. He believes that in future electric energy will be transmitted by superconductors and suggests making them in the form of giant tubes filled with liquid helium to supercool them. Liquid helium is frictionless so vehicles immersed in it may run at very high speeds.

It is doubtful, however, whether it is feasible to fill a giant tube with costly helium to make it superconductive. Would it not be more efficient to use superconductivity and such a tube in an arrangement carrying a magnetically suspended train through the tube evacuated to a subatmospheric pressure?

One such system, called Planetrun, envisages a magnetically suspended train moving through a pipeline at a low pressure. The thrust is generated by the pressure difference at either end of the vehicle. The tube inside which the vehicle moves is sectioned into locked compartments. To begin with, all the compartments are at different pressures so that the pressure falls in the outward direction. These pressure drops propel the vehicle until in compartment No. 50, for example, the pressure is only 98 Pa, which corresponds to atmospheric pressure at an altitude of 50 km. This fairly low pressure is established

for the remaining length of the tube, and the accelerated vehicle pierces it at enormous speed. When the vehicle is on its way back, the pressure settings in the compartments are obviously reversed.

The acceleration down the initial section is limited by passenger comfort. For the analysis, the largest allowable acceleration was assumed to be $1g$. This is not small since it doubles a passenger's weight. In this case, a vehicle is accelerated in 10 minutes to 22 500 km h^{-1}. Obviously at such speeds the train can only be operated for long distance travel. The inventors of the system suggest it for the 3950-km long New York to Los Angeles line. Taking into account the time needed for deceleration, the train will take 31.5 minutes to cover this distance at an average speed of 8350 km h^{-1}.

The construction of such a system is an extremely involved engineering challenge. It is not easy to provide for both the acceleration and braking of such a vehicle. However, the most challenging problem, both technologically and economically, is the construction of the sealed large-diameter pipeline extending for a great distance. Of course, it is true that progress in pipeline technology has been dramatic for both gas and oil, and that the first pneumocontainer transmission lines have appeared. Still, the construction of a tube carrying wheelless vehicles at space speeds is theoretically feasible but far from practical at present.

No new mode of transport can exist in isolation from the others. The designer of a new vehicle must match its speed with that of other vehicles, and moreover, with the pace of life. To

have jet passengers going home from an airport in a cart is absurd. But even accounting for the faster pace of life and vehicles accelerated by the technological revolution, conventional types could hardly match tube trains even in a few decades. In addition, an obvious shortcoming of the tube trains is that they are in constant conflict with the environment: the trains must be sealed from the atmosphere by a pipe. Also, at enormous speeds the trains would demand outstanding stability and accurate alignment of the pipeline, which is an enormous engineering challenge in view of the length of the route and the various types of terrain and seismic hazards encountered thereon.

For the same reason projects involving gravity vehicles and routes driven through the globe along chords also are not feasible.

Supertrains face never ending engineering problems which make the project cost snowball and project viability uncertain—the economic efficiency criterion comes to the fore. In addition, the final dimensions of the Earth confine the growth of the vehicle's speeds. On the other hand, future vehicles will have to transport at high speeds and over large distances ever increasing numbers of passengers.

Consider now those projects where aerodynamic drag can be eliminated to a considerable degree by elevating the system to high altitudes. We have already mentioned that the trend to higher altitudes is limited, on the one hand, by the rarefied atmosphere in which jet engines do not have enough oxygen to "breathe" and the use of rocket motors is very expensive and, on the

other hand, by the proximity of the ozone layer which protects life on Earth from a lethal section of the Sun's radiation. Generally, we want to decrease air drag in order to improve the economic efficiency of the system by lowering fuel expenditure.

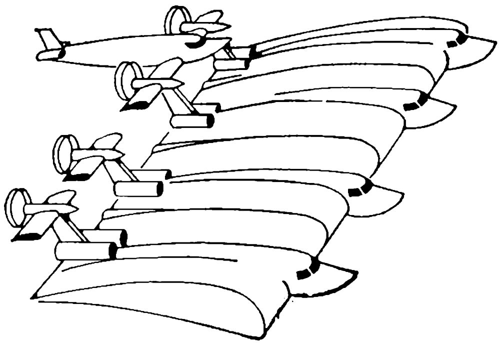


Fig. 17

H. Smith of the University of Pennsylvania (USA) has suggested an aircraft relay project. The base aircraft is a giant flying wing (Fig. 17) that can carry up to 4000 passengers and is permanently air-borne. The wing is in several modules. Each module is an airplane that can fly independently. Passengers, freight, and fuel are brought aloft by the smaller planes operating in a shuttle mode. The author of the system says that his wing configuration offers laminar flow-around, reduced drag and relative weight. The system would cut down the fuel consumption in the air lines by 87%, and relieve the pressure on the larger airports because shuttle flights of the

auxiliary planes should use small airfields. As a result operating costs would be decreased by 35%.

Projects involving huge flying platforms revolving around the Earth at high altitudes or covering large regions are feasible in principle, but they would require the traffic control and surface maintenance services be rearranged severely, and our social structure be changed accordingly on the planet. Therefore in the immediate future these projects will remain impractical.

Another global project concerns a space lift as suggested by a Leningrad engineer Yu. Artsutanov. The key element in the project is a 35800-km high tower, the summit of which would move through space at about 3 km s^{-1} (Earth orbital speed). This is the height of a geostationary or 24-hour orbit, in which a satellite remains stationary over a certain point of the Earth's surface. At the tower summit the centrifugal force of rotation balances the weight of a body brought there from the Earth. Once a body leaves a tower, it becomes an Earth satellite. Hence, a spacecraft should be taken to this altitude and then Earth's rotation helps to insert it into orbit. A satellite in synchronous orbit connected with the ground by a cable could be used instead of the tower.

What are the advantages of the space lift? When satellites are placed into orbit by rockets, the centrifugal force of the Earth's rotation is taken into account, and the rocket's path is chosen accordingly. The principal advantage of the lift is that electrical energy fed by a cable inside the lift could be used to elevate the craft to the tower summit and to launch it into orbit. As a

result the craft no longer needs a rocket engine or fuel tanks. Note that rocket fuel takes up most of a rocket's gross weight.

Naturally we want to know—whether the construction of such a lift is practically feasible. Can it sustain the stresses due to its own weight? At present the superstrong materials that would be needed for such lift do not exist. But theoretically they can be produced. The idea of a space lift poses some interesting and challenging problems. Several experts have suggested that some of lift's load could be taken by air balloons that would support the lift structure all over its height, or provide the lift force inside the structure. To accommodate for the latter proposition, the cross section of the lift should be increased, and the transport cabins could then be propelled inside the lift rather than outside. As for the wind loads, they can also be used to generate energy and stabilize the lift structure.

G. Pokrovsky has suggested launching spacecraft by using the centrifugal forces of an asteroid spun very rapidly. Arthur C. Clarke, the British scientist and science fiction writer, has decided to use rotation of galaxies for this purpose.

P. Berg, a British radio astronomer at the Jodrell Bank observatory, has recently reported the experimental evidence on the Universe's rotation. This gives us some hope that projects that harness centrifugal forces for launching space objects may not cease.

To date the problems of mass passenger transit at high speeds are being solved by airbuses. However, their wide use raises complicated problems associated with the need for fast transportation

of large numbers of passengers from the city to the airport and vice versa, and for the location of large airports far from the city.

The prime advantage of air transport is its ability to reach any point on the globe—the atmosphere embraces us everywhere. Airbuses are certainly helpful in solving the problem of mass passenger transit over large distances, but their maintenance is very expensive. As a result, it has been suggested that we should use another medium—water. The oceans and seas cover about four-fifths of the Earth's surface. From time immemorial the seas have been used to link continents, and the vast water surfaces have been travelled by seamen on long voyages. Now they must be used for passenger and freight transportation, but on a new technological basis and at higher speeds. A new turn in the evolutional spiral demands qualitatively new solutions, but only those which can integrate the latest achievements in the leading fields of science and technology will qualify. This requirement accords with the dialectics of transport development.

Flying above the Waves

Why are ordinary displacement ships so slow? Simply because at higher speeds displacement ships face a rapidly increasing power requirement which may be proportional to the third, fourth or even higher power of the speed. How then could water transport be made faster?

The designers of hydrofoils and hovercraft do so by lifting the ship's hull out of the water and into the air which is 800 times less dense. There

is, however, another way and that is to use the surface effect, as it is done in guided ACVs, but this time over water.

In the 1920s, aviators discovered the ground effect of the Earth's surface (screen effect). Heavy airplanes either refused to land or suddenly ascended as if getting additional lift. A British airplane the *Turrent Triplane* crashed on takeoff, and the *Swallow* monoplane was hardly be controlled with extended flaps. As soon as the ground effect disappeared at greater altitudes, the aerodynamic lift dropped and the engine could not generate enough power for the flight. The airplane therefore crashlanded.

A low-flying ground-effect machine, or "screen-plane", is capable to carry greater payloads than an airplane of the same mass. Consequently, either the machine should have supporting wings or its body should be an aerofoil-shaped device. The smaller the hover height, that is the closer the machine flies to the water's surface, the stronger the ground effect and the greater the lift. As a result the power requirements for its support are sizeably lower than those of an airplane after take off. A ground-effect plane has a high lift-to-drag ratio which is at least twice that of hydrofoils and ACVs. The efficiency of the machine increases with speed and size. The machine is designed to be buoyant when waterborne, taking off from and launching on the water surface.

Screen-planes over 1000 tonnes in mass and with a cruise speed of 700 km h^{-1} have been designed. However, these projects face many unsolved problems which prevent them from being

practically realized. Some of these problems are covered in *Ships and Navigation of the Future* by the German authors R. Schönknecht, J. Lüsch, M. Schelzel, and H. Obenaus. They write: "The effect of a close bearing surface, as any dynamic phenomenon, only becomes noticeable at high speeds. To acquire these speeds a ground-effect plane should be greatly accelerated when it starts, which requires extremely high thrust. This thrust cannot be generated by the power plant the machine needs for its normal flight. Therefore, screen-planes should have special takeoff boosters that are switched off once the craft is moving at the desired cruise speed. It would be best for the boosters to be jet engines or even rocket motors which can generate large thrusts for short periods of time. This feature of ground-effect craft should be taken into account when evaluating their potential application. Because each takeoff requires large power, the most feasible application for these craft, on economic grounds, seems to be on long-range transocean routes".

The author of this book has suggested a project of a screen-plane system which differs from the existing systems in that it can solve the problem of high takeoff powers. In this design (Fig. 18), the ground-effect machine (1) supported by an air cushion accelerates along a track (2). Depending on the vehicle's mass and size the supporting track may be made up of two or more rail beams. The aerofoil area of the wings (3) is varied to balance the lift. The propulsive power may be drawn from an aircraft engine with pusher or tractor propellers or jet engines (4). It

would be sound to place the jet engines in troughs (5), like in a winged TACV, to gain additional lift from their high-speed jets. Having been accelerated, the craft slips off the track and continues its flight across the water.

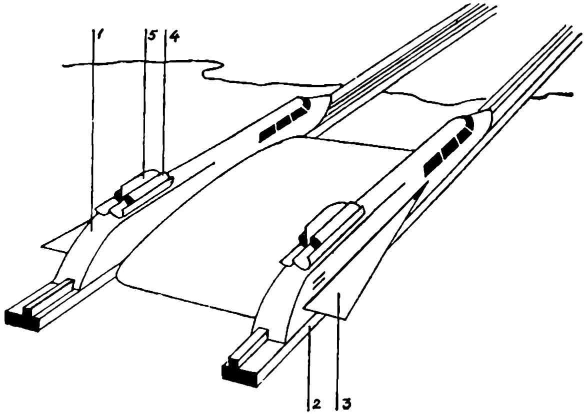


Fig. 18

The cruise speed of the vehicle is estimated as 500-700 km h^{-1}. A further increase in speed is associated with considerable growth of power requirements to overcome the aerodynamic drag. The available speed margin may be used to increase the hover height by using the oncoming aerodynamic head thus enabling the craft to clear rough sea better. For a safe and comfortable ride, the craft should not touch the waves. If a stormy sea with high waves is ahead, the craft can use its speed to avoid the area. Moreover the departure time can be adjusted according to the

weather forecasts for the route as broadcast by weather satellites.

The high speeds of the craft can provide very high pressure in the air cushion. Because the craft's lift is defined as the product of the pressure by the platform area in flight, the payload of the craft will be measured by tens or even hundreds of thousands of tonnes, the specific power of the power plant obviously decreasing for larger-size machines.

The project involves various methods of producing the air support relative to the guide track beams over the acceleration section as functions of the craft's size and design concepts. The cushion can be produced by onboard fans, stationary compressor stations, compressed-air balloons feeding the air at high pressure into the craft's carriage, or last but not least, using a dynamic head. Depending on the operating speed, the system provides for the automatic redistribution of the available plant power for thrust or lift. When the craft leaves the track and begins its flight over the water the carriage components, that were on the guide beams are retracted into the hull to improve streamlining.

The craft's fans are also used for landing when they produce an air cushion in the craft's landing gear. When the machine ditches, it decelerates and lands on an air cushion, it then operates like a conventional displacement ship. Over still water in a bay, the craft's own lift power will be enough to hover and so supported on an air cushion the craft can be towed to the launch pad and threaded onto the guide track for the return flight.

The project also considers how the craft can take off after an emergency landing on water. This will require additional boosters for the take-off thrust and additional power or compressed-air balloons for the air cushion to support the craft during the acceleration. Multi-hulled designs have been considered as these provide good stability and ensure that the craft cannot capsize after an emergency landing on rough seas.

The system appears to be promising and efficient in terms of the performance criteria we outlined earlier. Its advantages make it a very attractive proposition for transportation community. It starts from a track, flies at aircraft speeds supported by the aerodynamic lift of a wing, and does so close to the water surface. It operates over seas and oceans, and its flight time and route can be mapped from space. The craft uses advances in aircraft, marine and over-land transport and aerospace technology to solve the problem of mass passenger and freight transit over large distances at appropriate speeds and economic efficiencies.

The World of Transport Today and Tomorrow

We can hardly imagine how many transportation modes, vehicles and mechanisms are now in existence. And each transportation mode has numerous modifications and models. The Soviet TV programme "You can do it yourself", where the author has been a member of the expert board already for more than a decade, has displayed and subjected to the criticism of the audience dozens of designs involving the wheel. It has

also covered numerous swamp and snow rangers, and a variety of off-the-road vehicles, be they rubber tyred, tracklaying, air-supported, jumping, crawling, and even dancing. All of them were not toys but rather models of vehicles devised to perform useful work. There have been as many designs for flying craft, underwater, and water-going craft.

Ever so each epoch has its characteristic modes of transportation which carry most of the passenger and freight traffic and which define the transportation policies of states.

Which methods of transportation are typical of our time? On the surface we have railway transport and automobiles, with buses, lorries and tractor-trailer combinations being important; in the air we have jet aircraft, short haul piston airplanes, and helicopters; and on the water, we have displacement ships for passenger, freight, and oil and gas transport, propelled by combustion or nuclear power engines, and finally hydrofoils and hovercraft.

Underwater transport is not yet a civilian transportation system, although underground pipeline transportation, primarily for liquefied gas and oil, deserves mentioning.

These are the most typical transportation forms in our time. They do not subject to change frequently. For example, combustion-engine displacement ships have now been in existence for many decades, but each form is continuously modernized. Our current progress in technology provides a basis for new forms of transportation, which may evolve more quickly than it was possible in the past. We may suppose that the im-

mediate decades will see some new modes of transportation, and a pipedream of today may predominate in the future.

Let us attempt a prognosis of transportation development over the next half-century and see what will be typical by the middle of the 21st century. Surface transportation will see super-speed trains with magnetic and air suspension. Air cushion vehicles will be used in undeveloped and inaccessible regions. Air traffic will be dominated by large jet aircraft, primarily air-buses, but airships will also find numerous applications. For cross-water routes the airliners' domination will be challenged by ground-effect planes whose time-tables and navigation will be controlled from space.

We have already evaluated extensively the factors used to assess the development potential of all the proposed transportation modes. Now we shall look at the potential of hydrofoils and hovercraft.

We have already pointed out that the key criteria in such an assessment are speed and payload capacity. The payload capacity of hydrofoil boats is determined by the lift their hydrofoils generate, which increases with the vehicle's speed and the submerged area of the hydrofoils. Because the lift is proportional to the square of the velocity and to the hydrofoil area raised to the first power, it is worth increasing lift by increasing the operating speed. Consequently, larger hydrofoils must be capable of higher speeds. A further increase in speed is, however, prevented by cavitation.

Cavitation is the spontaneous formation of

small transient cavities (bubbles) in the body of any fluid subjected to severe changes in pressure. This phenomenon breaks down the continuity of the fluid. When the pressure of a liquid is reduced below its vapour pressure, any gas or vapour it contains will immediately be converted to the gaseous state. The vapour appears as tiny bubbles that form and then collapse violently as they enter a higher-pressure area.

Bernoulli's equation shows that a liquid's pressure and its velocity are inversely related. The submerged foil profile is such that in motion the highest speed, and hence the least pressure, occur above the foil. As the speed grows bubble formation occurs in this area. The bubbles move to the trailing edge of the foil and then enter a higher-pressure area and collapse rapidly. The collapsing of cavitation bubbles causes a succession of hydraulic shock waves associated with high pressure and temperature. It is the shock waves emanating from the collapsing cavities that can cause damage, and if the cavitation is allowed to occur at a liquid/solid interface the solid surface may be rapidly eroded. This is especially likely with the foils made of soft metals. Cavitation also causes the craft to vibrate badly.

Apart from the cavitation large submerged-foil ships face an energy barrier. The larger and heavier vessels demand higher speeds and the power requirements rise in proportion to the product of its operating weight and speed. In the early 1960s, in the United States, some 1000-tonne hydrofoils were designed. In order to drive these craft at 120 km h^{-1} a power plant with a power

of 45-60 MW would be needed. A 3000-tonne vessel propelled at 280 km h^{-1} would require 300 MW. These enormous power requirements indicate that superhydrofoils cannot be practical in the immediate future.

Let us now have a look at how the requirements for higher speeds and payload capacity are realized in air cushion vehicles. The pressure under the ACV's base is from 3 to 5 kN m^{-2}. It causes a 10-cm water surface depression per unit kN m^{-2}. The operating height of the air cushion depends on the height of the waves: obviously the craft should hover above the waves.

The trend to higher air cushions entails higher air losses from the plenum chamber and therefore higher power requirements. The air escapes across the perimeter edge of the chamber. Because the cushion's lift is proportional to the product of the cushion pressure and the platform area, the optimal shape of an ACV chamber is a circle, a circle's area-to-perimeter ratio increasing for larger craft, as the first grows as the radius squared and the second as the linear radius. Accordingly, given a hover height, a larger ACV will offer a greater payload capacity and lower specific power requirement for air support.

To prevent the escape of cushion air, ACV designers employ air or water peripheral curtains, configure the air recirculating systems in the form of labyrinth seals or jet recirculating arrangements, install peripheral skirts of flexible material to go from the craft base down to the ground or water, or provide the craft with either rigid or inflatable sidewalls, called skegs. Skegs project right down into the water along both

sides of the craft, thereby effectively preventing the escape of cushion air except at the bow and stern. The two latter places are sealed by a system of flexible skirts as they are in an amphibious ACV. The advantage of the sidewall is that it seals the sides of the cushion with virtually 100-percent efficiency, and it does so with no expenditure of power in pumping peripheral curtains of air. A further advantage is that the sidewalls have considerable buoyancy and give a sidewall ACV a high degree of automatic stability, which the high-riding amphibious type must get by other methods. But they also have drawbacks in that they drag through the water and the craft loses its amphibious capacity—it cannot, for example, climb a shallow bank to unload.

The largest ACV so far built is the French

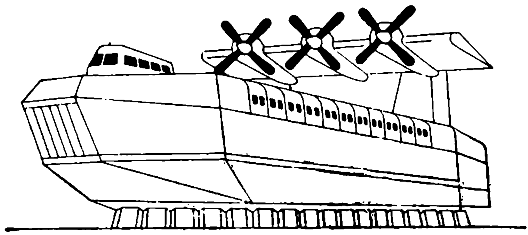


Fig. 19

Naviplane 500 (Fig. 19). This can carry 400 passengers and 45 cars and has been in regular operation since mid-1977. Today some 50 per cent of all traffic across the English Channel is effected by hovercraft. The specific power of *Naviplane 500* is rather high and amounts to 50.8 kW per tonne of gross weight.

As the vehicle size increases its power requirement per tonne decreases, and for example, a 10 000-tonne vessel may only need 25 kW/t. But in this case the engines must also develop enormous power and the fuel stored for a 20-hour trip would amount to 30% of the vehicle's total weight. Therefore, such a vehicle will only become practicable if powered by nuclear fuel.

Sidewall ACVs demonstrate much higher economic efficiencies. For example, a 5000-tonne skeg ship is a fairly competitive alternative to displacement ships because of faster operating speed, up to 200 km h^{-1}.

The current investigations of submarine vessels for liquid fuels and multi-hulled vessels also show considerable promise.

There are reasons to believe that a vehicle may soon emerge which will travel at low speeds but will catch the imagination of the layman. These machines will be envisioned in robots, that will be indispensible in many human endeavours. Now, for instance, robots are being considered that can move across vertical walls and even ceilings. Tomorrow such robots will become commonplace.

Unusual vehicles will also be conceived for space exploration. In the atmosphere of Venus, which is 60 times as dense as the Earth's atmosphere, aerostatic craft will be efficient. The temperature lapse rate of the venerian atmosphere can be used for vertical travel of such craft, as its volume and the environmental temperature, and thus the buoyancy can be appropriately related in the craft concept.

Even old ideas rejected in the past may be re-

vived. Jules Vern's idea of launching a Moon mission from a gun has been devastatingly criticized. A man would be collapsed within moments of the launch. But is it so necessary to shoot men into space? Most space exploration, sounding, and other rockets now launched carry instrumental gear onboard, and these can withstand large overloads so a gun launch will not harm them. So it is likely that Jules Vern's old idea will turn out to be useful in future space research.

It is not easy to imagine today that in fifty years hence a space lift may begin to deliver payloads into orbit. But it is beyond doubt that by that time mankind will be carrying out some wonderful projects.

These new forms of transportation will not completely replace present vehicles, such as railway trains, automobiles, displacement ships, and helicopters. They will back up existent transportation modes, and present competitive alternatives in the areas where they are more efficient. The vehicles now typical will not be conserved in their present form but will be improved.

Technological progress is omnipresent and the achievements of space manufacturing, electronics, computing, materials science and other fields will find their way into transportation. For this purpose the co-operation of experts in various fields and countries is necessary. No one will lose from mutual efforts, for sharing ideas enriches every participant. This approach brings forth the need for international collaboration on transportation problems because transport is important for everyone.

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SCIENCE FOR EVERYONE

G. Zelkin, Cand. Sc. (Eng.)
Flying Trains

We can hardly imagine how many transportation modes are now in existence. It is life that motivates the advent of new vehicles. Our current progress in science and technology provides a basis for new forms of transportation. We may suppose that the immediate decades will see new modes of transportation, and a pipedream of today may predominate in the future. Surface transportation will see superspeed trains with magnetic and air suspension. Air traffic will be dominated by large jet aircraft, primarily airbuses, and airships will also find numerous applications. For cross water routes hydrofoils, hovercraft, and ground-effect machines will be used whose time-tables and navigation will be controlled from space.

The book discusses the development of a number of promising vehicles, such as fast wheelless trains, and shows the perspectives of their advancement. The material of the book is based on a great deal of facts concerning the latest achievements in the field.

The book is intended for those who are interested in the history of transportation, new technical ideas, and the prospects of transportation technology.

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